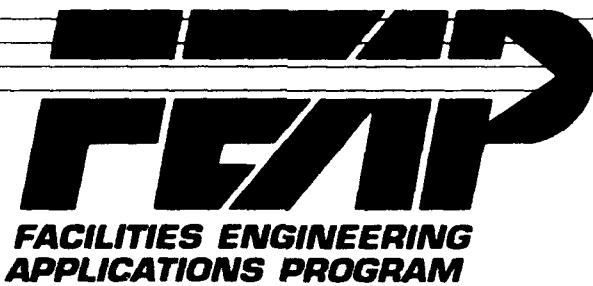


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FEAP TR-FM-93/06
July 1993



TECHNICAL
REPORT

(2)

Demonstration of Polyscann Ultrasonic Butt-Fusion Inspection System for Polyethylene Pipes

by
Orange S. Marshall, Jr., and James B. Hunt
U.S. Army Construction Engineering Research Laboratories
Champaign, IL 61826-9005

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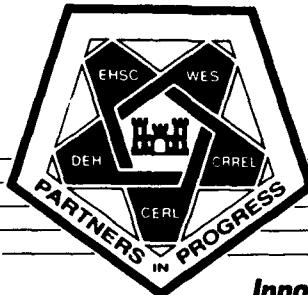
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<p>This report describes the demonstration of the Polyscann Ultrasonic Butt-Fusion Inspection System and laboratory research into its effectiveness as a quality control tool for installation of polyethylene pipe. In the demonstration, conducted at North Fort Hood, TX, 13 sections of 8 in. diameter polyethylene pipe were assembled and tied into a previously installed 8 in. gas pipeline. The system was successfully used to inspect each new butt-fusion joint in its entirety, and provided a computerized record of joint cross-sections and status. Laboratory tests indicated that the equipment results were mostly reliable, but it could not detect a low-density weld contaminant such as dried grass.</p>			
<p>Benefits of the Polyscann system include its nondestructive evaluation technology, capability of evaluating all joints without interrupting pipeline productivity, datalogging capabilities, ease of use, and ability to identify necessary repairs before the pipe is buried.</p>			
<p>After this demonstration was concluded, the manufacturer discontinued the system that was tested, and is redesigning it to be portable by one person and capable of detecting low-density contaminants such as grass. Price and release date for the updated system are pending.</p>			
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FOREWORD

This project was conducted for the U.S. Army Engineering and Housing Support Center (USAEHSC) under the Facilities Engineering Applications Program (FEAP), Work Units FEAP-MB-M41 and FEAP-MB-F32, "Demonstration of Polyscann Ultrasonic Butt-Fusion Inspection System." The USAEHSC technical monitor is Mr. Malcolm McLeod, CEHSC-FU-S.

The FEAP demonstration was performed by the Engineering and Materials (FM) Division of the Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). Dr. Paul A. Howdyshell is Chief, CECER-FM. Dr. Michael J. O'Connor is Chief, CECER-FL. The USACERL technical editor was Gordon L. Cohen, Information Management Office.

Mr. Leon Howard, Operations and Maintenance (O&M) manager for the Directorate of Engineering and Housing (DEH) at Fort Hood, TX, and James Wilkins, pipefitter leader for the fuel distribution group of the exterior plumbing shop of the maintenance division, were invaluable to the successful completion of this work.

LTC David J. Rehbein is Commander of USACERL, and Dr. L.R. Shaffer is Director.

CONTENTS

	Page																				
SF298	1																				
FOREWORD	2																				
LIST OF FIGURES AND TABLES	4																				
1 INTRODUCTION	7																				
Background																					
Objective																					
Approach																					
Safety																					
Mode of Technology Transfer																					
2 ULTRASONIC TESTING THEORY	9																				
3 ULTRASONIC TESTING PROCEDURE OF BUTT-FUSION JOINTS	12																				
Equipment Installation																					
Polyscann Testing																					
Transfer and Use of Polyscann Data																					
4 LABORATORY TESTS	24																				
Specimen Preparation																					
Polyscann Evaluation Results																					
Tensile Testing																					
Pass-Fail Criteria																					
Laboratory Analysis																					
5 DEMONSTRATION OF THE POLYSCANN SYSTEM	33																				
Polyethylene Butt-Fusion Inspection Process																					
Benefits of the Polyscann System																					
Drawbacks																					
6 CONCLUSIONS AND RECOMMENDATIONS	40																				
METRIC CONVERSION FACTORS	40																				
REFERENCES	41																				
APPENDIX A: Tabulation of Polyscann Inspection Results for Pipes Tested in the Laboratory	42																				
APPENDIX B: Tabulation of the Laboratory Mechanical Tensile Test Results	43																				
ABBREVIATIONS AND ACRONYMS	51																				
DISTRIBUTION																					
DTIC QUALITY INSPECTED 5																					
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A-1																					

FIGURES

Number		Page
1	Schematic of Pulse-Echo Method	10
2	Graph of Transducer Position vs Echo Intensity	11
3	The Polyscann Ultrasonic Butt-Fusion Inspection System	12
4	Stationary Ring	13
5	Properly Positioned and Secured Ring	13
6	Seals Requiring Lubrication	15
7	Attachment of Rotating Assembly	15
8	Motor Module	16
9	Connection of Cables and Hoses	16
10	Electronic Control Module	17
11	Support Module (Couplant Fluid Pump)	17
12	Liquid Crystal Display on ECM	18
13	ECM Battery Charger	19
14	<i>TDWPOLY</i> Main Menu	19
15	Upload Options	20
16	Save Options Screen	21
17	Inspection Data Screen	22
18	View Selection Options	22
19	Inspection Report Screen	23
20	Inspection Report Print Options	23
21	Sample Joint With Dirt in Weld	25
22	Inspection Report Screen for Weld Made With Excessive Heat	25
23	Inspection Report Screen for Weld Made Under Insufficient Pressure	26
24	Sample Joint With Grass in Weld	26

FIGURES (Cont'd)

Number		Page
25	Specifications for Sample Joints Used in Tensile Tests	27
26	Specimens for Tensile Testing	28
27	Typical Load-Versus-Displacement Graph	28
28	Example of Necking in Joint Specimen	31
29	Example of Non-necking Failure in Joint Specimen	31
30	Pipe End Removal	34
31	Butt-Fusion Machine	34
32	Trimming Router in Place	35
33	Teflon-Coated Heating Plate	35
34	Molten Bead at Interface of Heating Iron and Pipe	36
35	Fusion Bead	36

TABLES

1	Minimum Values for Pass/Fail Criteria for Pipe Grades Tested in the Laboratory	30
2	Pass/Fail Results of the Various Test Criteria for The Pipe Samples Tested in the Laboratory	32
3	Costs for Polyscann System, 1990	39

DEMONSTRATION OF POLYSCANN ULTRASONIC BUTT-FUSION INSPECTION SYSTEM FOR POLYETHYLENE PIPES

1 INTRODUCTION

Background

Polyethylene pipes offer some distinct advantages over steel when used to carry natural gas between facilities on Army installations. Polyethylene pipes are preferred in many cases because they are less expensive than steel. Polyethylene pipes do not corrode, so they do not require the resources and manpower necessary for maintenance of cathodic protection. The joint weld integrity, however, causes great concern among users. The only approved means of determining if the butt joint at each end of a pipe section is properly intact is to wait and see if it leaks, or to use a destructive method to test the joint. Leaks present unacceptable health, safety, and environmental hazards. In addition, regulations preclude repair of gas pipelines once they are in service; since replacement is the only means of leak repair, reliable nondestructive testing (NDT) of pipe joints is vital to preclude unnecessary replacement of new pipelines. A nondestructive means of inspecting all pipe butt joints is needed to prevent danger to personnel, property, and the environment caused by pipeline joint rupture due to poor workmanship.

Objective

The objective of this work was to demonstrate the use and evaluate the effectiveness of the Polyscann Ultrasonic Butt-Fusion Inspection System for an 8 in. polyethylene natural gas pipeline at an Army installation.

Approach

The Polyscann system was chosen for this demonstration because Fort Hood was planning to replace an 8 in. steel gas pipeline with a polyethylene one, and wanted to test the new butt-fusion joints with an ultrasonic system. T.D. Williamson, Inc. was the only known source of commercially available ultrasonic testing equipment that could be used on 8 in. polyethylene pipe.

The approach used to perform the work was to (1) purchase a Polyscann Ultrasonic Butt-Fusion Inspection System, (2) become familiar with the system's operation, (3) prepare both good and flawed butt-joints and evaluate them in the laboratory using the ultrasonic inspection system, (4) perform destructive evaluation of the flawed butt-joints to evaluate the system's sensitivity and reliability, and (5) through the Army's Facilities Engineering Applications Program (FEAP), conduct a field demonstration at Fort Hood, TX, on an 8 in. polyethylene gas pipeline as it is installed.

Safety

The Polyscann Ultrasonic Butt-Fusion Inspection System must be used following the manufacturer's instructions and normal safe working practices. No extraordinary hazards exist that would not be covered in these features.

Mode of Technology Transfer

This technology will be disseminated by publication and distribution of a FEAP technology user's guide (covering procurement specifications, sources of supply, and descriptions of system uses), and a FEAP informational flyer describing the system for potential users. In addition, a briefing on the system and field experiences will be presented at Corrosion Control Users Group meetings and through Huntsville Division, at annual PROSPECT courses for civil works and facilities engineer corrosion mitigation, which are attended by personnel from Directorate of Engineering and Housing (DEH), major Army Commands (MACOMs), the Office of the Chief of Engineers (OCE), the Army Corps of Engineers (USACE), and the U.S. Navy. The technology will be further disseminated through FEAP bulletins and *DEH Digest* articles. Also, changes to Corps of Engineers Guide Specifications (CEGS) Section 02685, *Gas Distribution System* (HQUSACE, February 1990), will be recommended to specify as a requirement ultrasonic testing of polyethylene piping by the pipeline installer.

2 ULTRASONIC TESTING THEORY

This chapter gives a brief overview of ultrasonic testing and the theory involved in that testing. It also relates the theory with what is occurring when a polyethylene butt-fusion joint is tested using the Polyscann Ultrasonic Butt-Fusion Inspection System.

The word *ultrasonic* comes from the latin words *ultra*, meaning beyond range, scope, or limit of, and *sonus*, meaning an audible sound. Ultrasonics are sounds beyond the range at which the human ear can detect it. Because hearing capabilities vary from person to person, there is no precise lower limit defined for ultrasonics. Also, while ultrasonic wavelengths shorter than atomic spacing (about 10^{13} Hz) may exist, they have no known practical application. Therefore, there is no precisely defined upper limit on ultrasonics, either.

Ultrasonics are used for many industrial applications. The ability of sound vibrations to do mechanical work is employed for such tasks as cleaning, welding, friction reduction, drilling, physical therapy, and liquids processing. The acoustical frequencies used in these applications are in the range of thousands of cycles, or Hertz (Hz), per second. Another pertinent characteristic of sound is its ability to travel through substrates without interfering with them structurally. This capability is used for applications such as measuring equipment, flaw detection, and medical condition sensing equipment. Their operating frequencies are in the milliHertz (mHz) or megaHertz (MHz) ranges (J.R. Frederick, *Ultrasonic Engineering* (John Wiley & Sons, Inc., New York, (1965) pp 2-7).

The ultrasonic method used for flaw detection was initially developed during World War I for locating objects underwater—particularly submarines. During World War II ultrasonic techniques were applied to nondestructive testing, or NDT. The NDT method is called the *pulse-echo* method because it transmits the ultrasound in pulses and detects the intensity of sound echoed back due to material boundaries, flaws forming a type of boundary in the material. Figure 1 is a schematic depicting the pulse-echo method.

The limitations of the equipment to detect flaws are threefold: the flaw (1) must provide a reflective surface, i.e., have a density gradient (difference) from the basic material being inspected, (2) must be oriented in such a way that a reflected sound wave will be intercepted by the ultrasonic receiver, (3) must be larger than the amplitude of the ultrasonic wave, and (4) must be struck by the pulse in order to reflect off of it. The distance from the transducer (sound transmitter and receiver) to the flaw surface can be accurately determined on the basis of the time it takes for a sonic pulse to travel to the flaw and echo back to the transducer.

The Polyscann Ultrasonic Butt-Fusion Inspection System uses pulse-echo principles in detecting flaws in butt-fusion joints of polyethylene pipes. The inspection system incorporates several transducers, that operate at a frequency of 2.5 MHz. Each transducer is focused to a different depth range in the pipe joint. A gasketed sleeve is installed around the pipe, then into the sleeve a sound-transmitting fluid is pumped to ensure coupling between instrument and pipe. Six transducers were used for the 8 in. pipe. Although there is a slight amount of overlap, each transducer is focused at a different depth through the 0.75 in. pipe wall. Also, each transducer is positioned to promote the best possible echo reception.

Figure 2 is a graph of the transducer position around the circumference of the pipe versus the echo intensity (wave amplitude) detected. The scale, based on the material density, is relative. A peak at 127.5 indicates an area of near half the normal polyethylene density and a peak at 255 indicates the density of air. Polyethylene is a crystalline polymer and has, by nature, a density gradient throughout, due to localized crystalline and amorphous regions, as well as other additives such as colorants, ultraviolet light stabilizers, processing impurities, etc. These all can provide a source of echo due to their density differences, producing a background sound level. Genuine flaws usually provide a much higher intensity

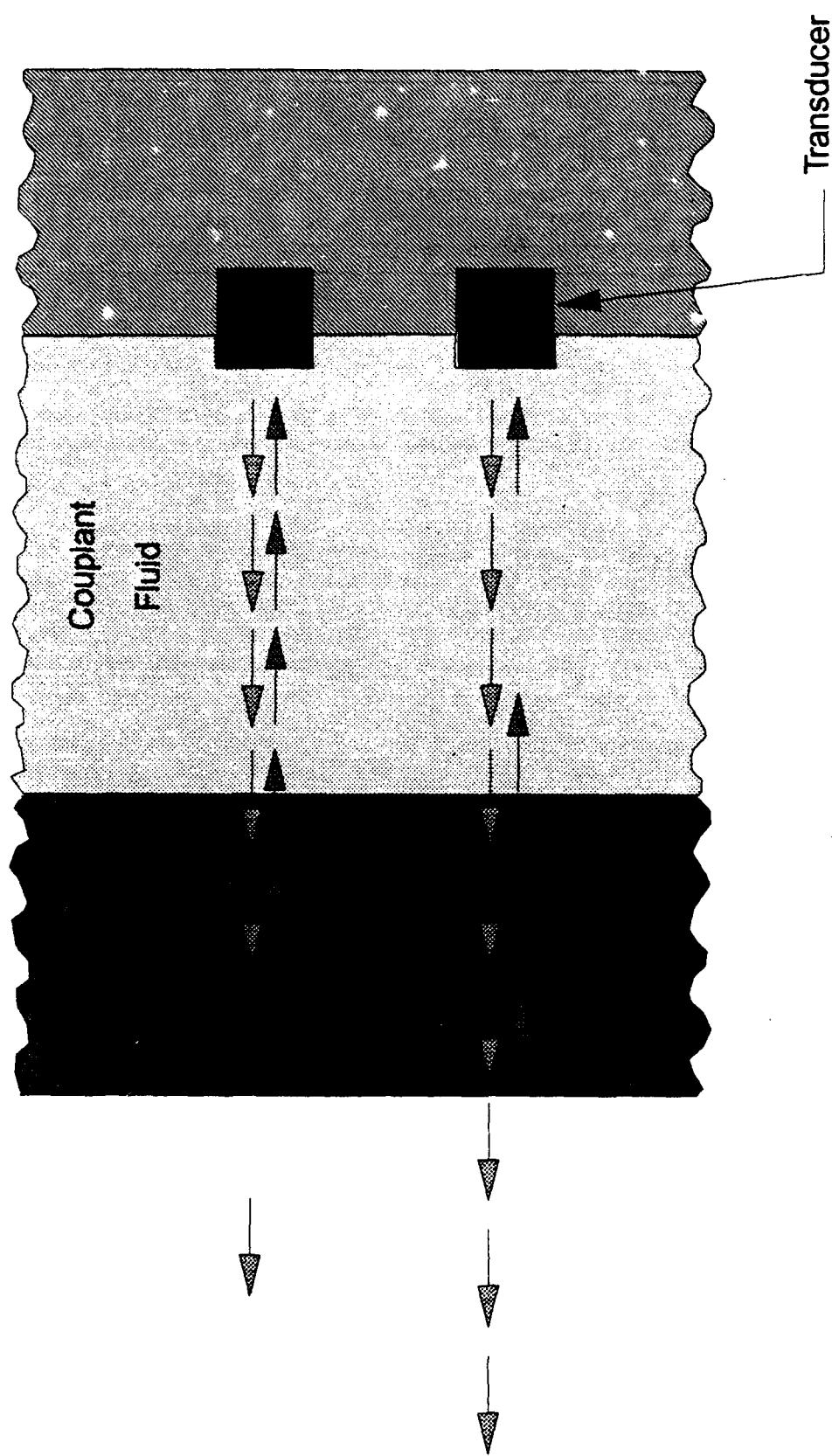


Figure 1. Schematic of Pulse-Echo Method.

of sound reflectance because of large density changes, so they can be detected by their intensities. The Polyscann equipment electronically filters all low-intensity echoes and records only those reaching at least 128 on the intensity scale on the report printout. The system reports a flaw if intensity exceeds 160. The two horizontal lines on each graph in Figure 2 represent these two threshold amplitudes.

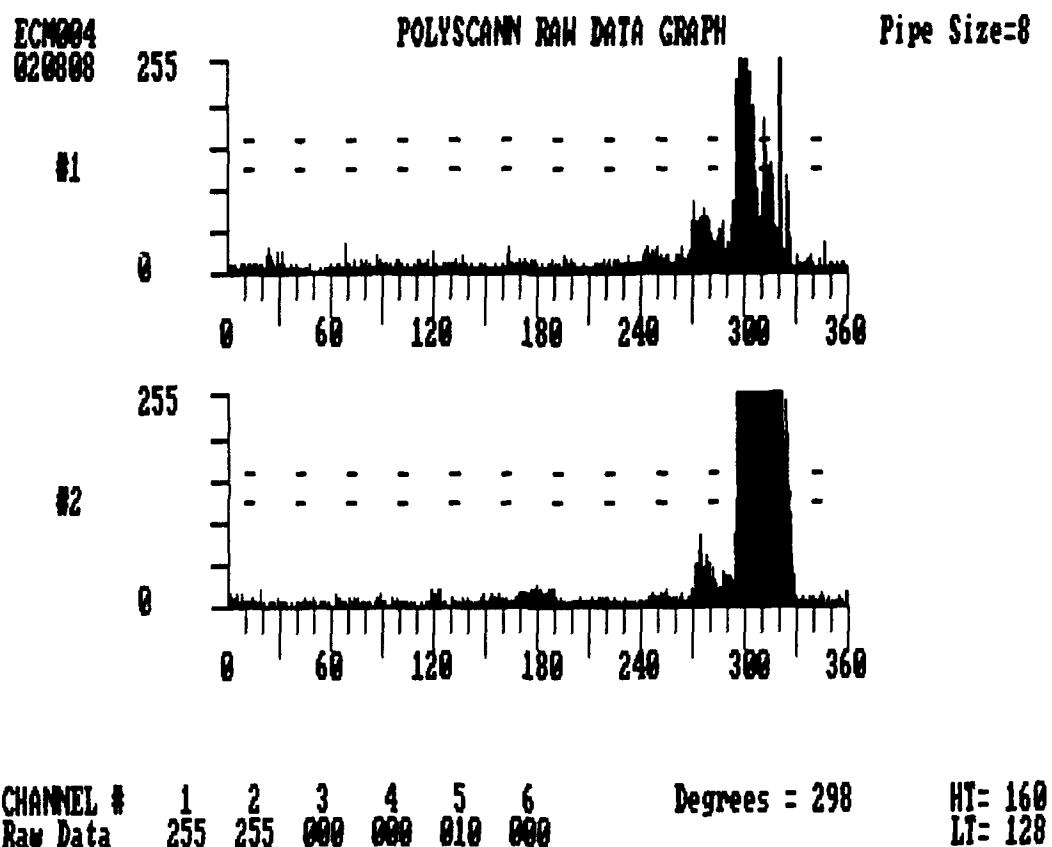


Figure 2. Graph of Transducer Position vs Echo Intensity.

3 ULTRASONIC TESTING PROCEDURE OF BUTT-FUSION JOINTS

This chapter describes the process used to perform inspections of butt-fusion pipe joints using the Polyscann system (Figure 3). The testing can be performed on any butt-fusion joint that has cooled enough for the butt-fusion equipment to be moved forward toward the next joint.

Equipment Installation

Before installing any of the inspection equipment, the outside of the pipe must be inspected for deep scratches, rough spots, and dirt. Any deep scratches or rough spots present should be smoothed out using a fine abrasive to prevent excessive loss of couplant fluid through the scratches during the inspection phase. Excessive loss of couplant fluid could result in erroneous test results. All dirt and pipe debris must be wiped clean with a damp cloth at least 6 in. on either side of the joint. This ensures that the couplant fluid is not contaminated. Contamination of the couplant fluid can result both in equipment reading errors and can damage the couplant fluid pump.

The stationary assembly is the first piece of equipment to be attached to the pipe (Figure 4). It is positioned by first extending the locator rod fully and adjusting the assembly so the motor module mounting plate is nearly level on top of the pipe section and the knife edge of the locator rod is centered over the fusion bead to be inspected. The two clamp latches on the side of the assembly are then closed to ensure that the assembly does not shift while closing (Figure 5). The position of the stationary assembly is very critical to assure that the ultrasonic transducers are aimed properly at the butt-fused pipe joint. Proper clamping of the assembly onto the pipe assures its proper position. Finally, the locator rod is retracted into its recessed position in the stationary assembly.



Figure 3. The Polyscann Ultrasonic Butt-Fusion Inspection System.

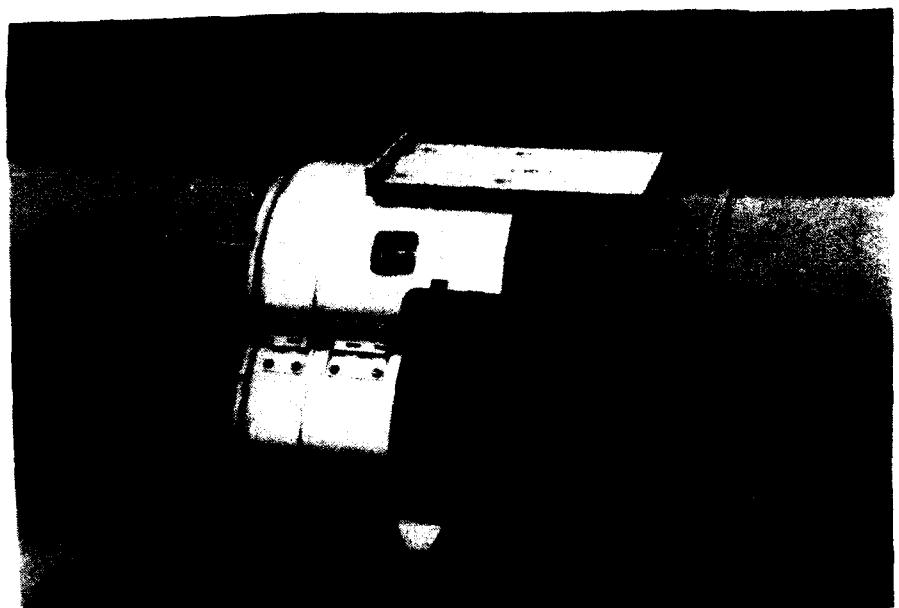


Figure 4. Stationary Ring.

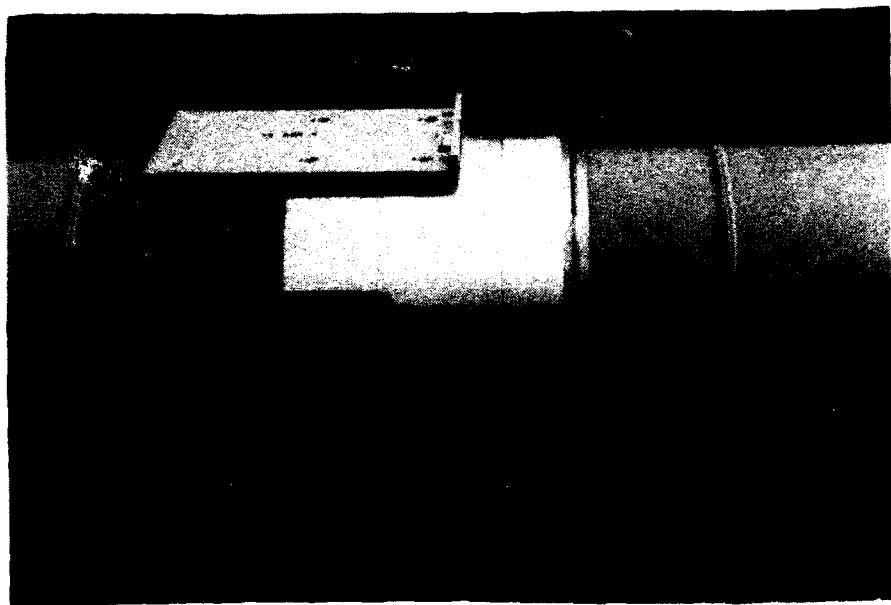


Figure 5. Properly Positioned and Secured Ring.

The rotating assembly is the next part of the inspection system to be attached. Before attaching it to the outside of the stationary assembly, the inner pipe seals (which contact the pipe surface) must be lightly lubricated with Polyscann seal lubricant. They should be lubricated before the first inspection of each day and again at every tenth inspection thereafter. In addition, before each inspection, a bead of Dow-Corning III Valve Lubricant and Sealant must be run from the ends of one pipe seal, along the plate seal, to the other pipe seal (Figure 6). If this is not done, excessive leaking of couplant fluid will occur, especially on 8 in. pipes, which will result in erroneous or unreliable inspection results. Finally, before attaching the rotating assembly, the transducer faces should be inspected to be sure there is no lubricant or dirt on them. (They can be cleaned using a lint-free cloth and couplant fluid.) The rotating assembly is attached by first aligning the rotating assembly wheels in the tracks of the stationary assembly and fastening the clamp latches on the rotating assembly side (Figure 7). The rotating assembly should then be rotated enough to assure that it rotates freely, and so its handle is positioned to the top.

The motor module is then attached to the mounting plate on the stationary assembly by pulling up on the bail handle and sliding it forward until the gears mesh and the mount pins engage. The bail handle is then released, which seats the bail pins in the mounting plate (Figure 8). It is sometimes necessary to move the rotating assembly slightly to get the gears to mesh and engage properly.

The last connections necessary in installing the Polyscann inspection equipment are to connect the cables and transfer hoses (Figure 9). The ring cable is connected between the rotating assembly and the electronic control module, or ECM (Figure 10); the support cable between the support module (Figure 11) and the ECM; and the motor cable between the motor module and the ECM. The couplant supply hose is connected between the support module and the bottom of the rotating assembly, and the couplant return hose is connected between the supply module and the top of the rotating assembly.

Polyscann Testing

When the inspection equipment has been assembled, butt-fusion joints can be inspected. The inspection is conducted by turning on the main power switch on the ECM and following instructions displayed in the liquid crystal display screen on the top of the ECM (Figure 12). The actual sequence consists of the following steps:

1. Press the "NEXT" key
2. Enter the operator identification (ID) code, a numerical value up to nine digits that identifies the inspection operator for future database sorting, followed by pressing the "ENTER" key
3. Press "NEXT" three more times
4. Press the number "1"
5. Press the "START/RESTART" key.

The couplant fluid is then pumped from a 1 gal. container in the support module into the rotating assembly, filling the reservoir. Once full, the rotating assembly rotates 180 degrees so the handle is on the bottom and then rotates the other direction 360 degrees inspecting the fusion joint. The rotating assembly then returns to the original setup position, and the couplant fluid is pumped back into the fluid container in the support module.

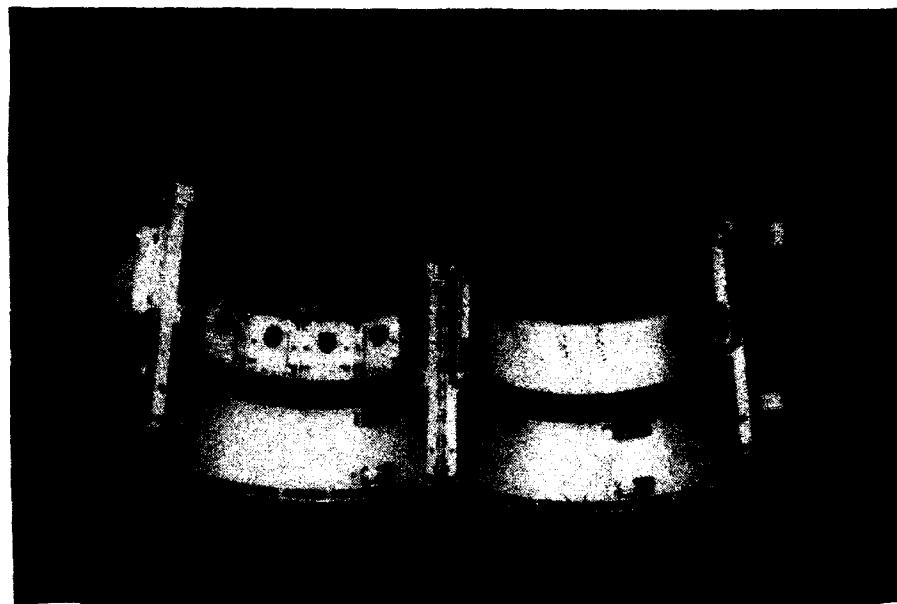


Figure 6. Seals Requiring Lubrication.

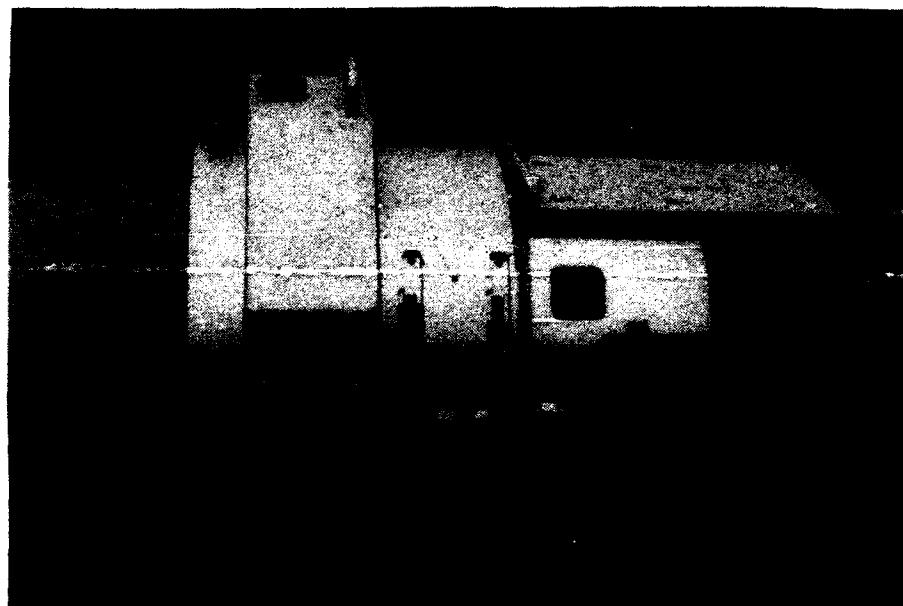


Figure 7. Attachment of Rotating Assembly.

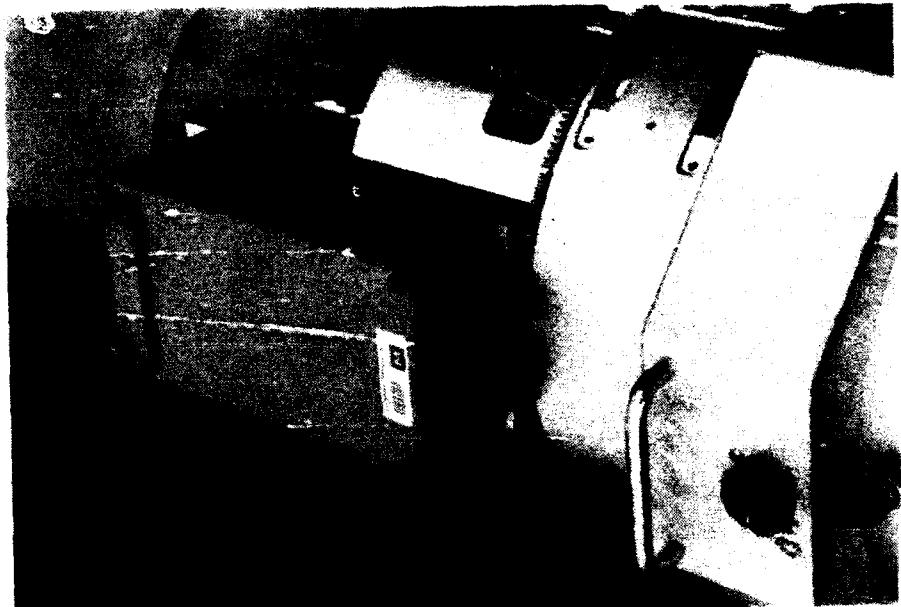


Figure 8. Motor Module.

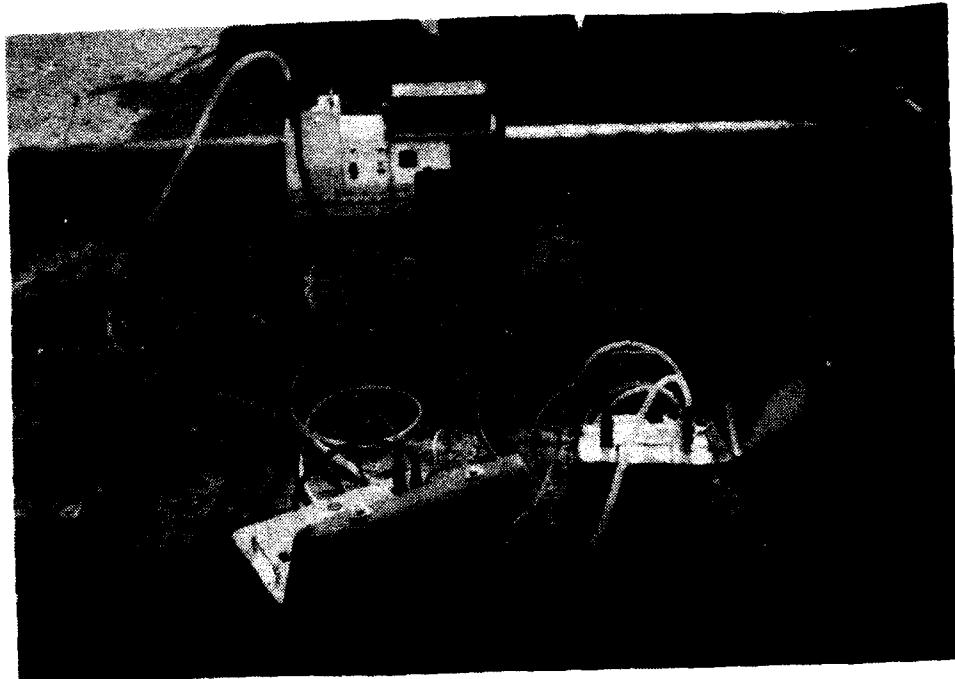


Figure 9. Connection of Cables and Hoses.

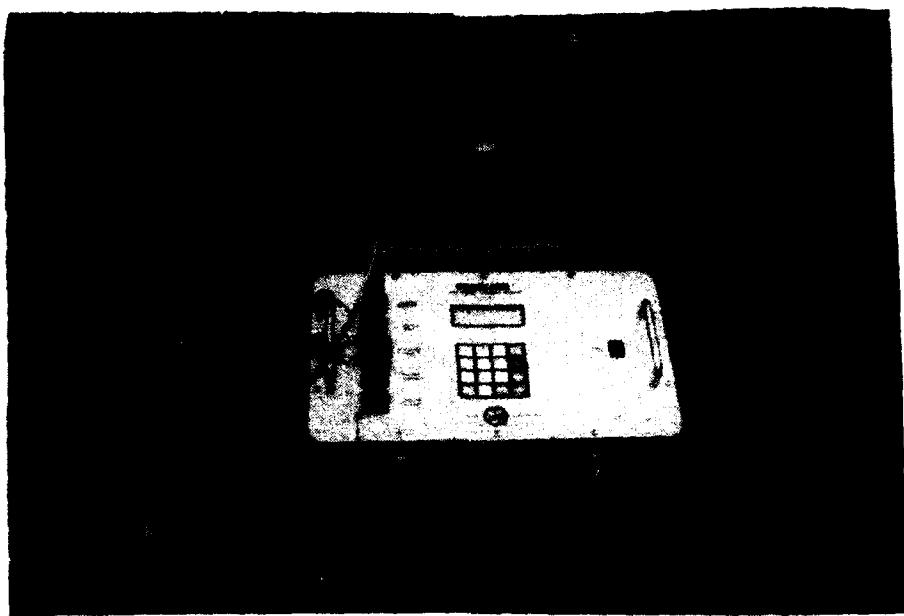


Figure 10. Electronic Control Module.

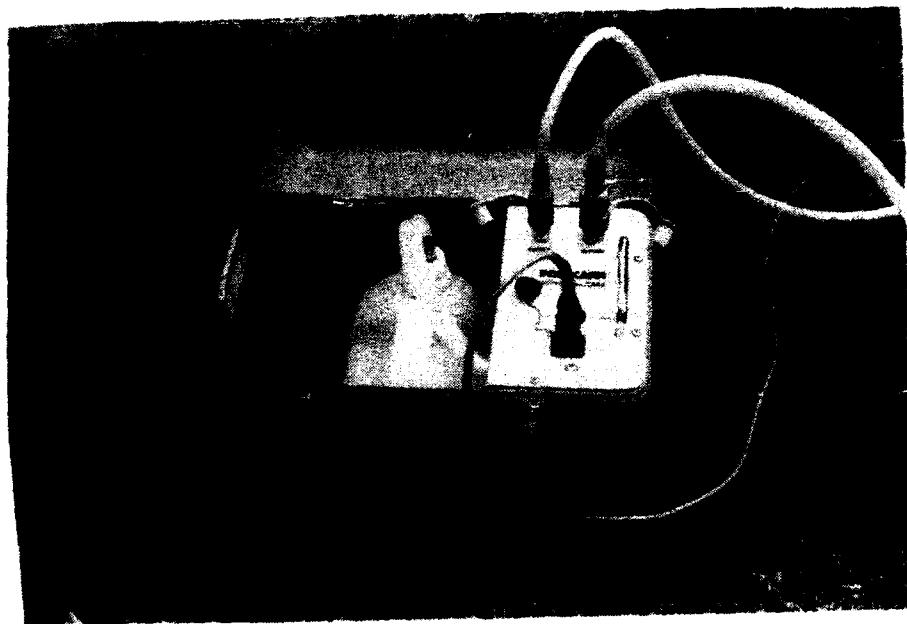


Figure 11. Support Module (Couplant Fluid Pump).



Figure 12. Liquid Crystal Display on ECM.

The ECM contains a rechargeable battery that holds enough energy to inspect 40 to 48 butt-fusion joints between charges. However, the manufacturer recommends that the batteries be recharged daily after completion of inspections regardless of the number. A battery charger (Figure 13) is supplied as part of the equipment set.

Transfer and Use of Polyscann Data

In addition to the test equipment previously described, the Polyscann system includes software for DOS-compatible microcomputers entitled *TDWPOLY*, designed for use with the ECM to download, display, or print inspection data. The software permits the cataloging of inspection data for permanent storage. Up to 120 inspections may be stored on a single 360K formatted diskette. The software program allows organization of the inspection data by operator, pipe size, inspection number, or combinations thereof.

The ECM has 120 memory locations, each of which can store an inspection. When the ECM is commanded to make an inspection, it first checks to see if memory is available. A memory location is available only if no other data occupy the location, or if the data has been downloaded. This prevents the overwriting of unsaved data. Once a record has been transferred, the ECM will allow that memory location to be overwritten with data from another inspection.

In order to download data from the ECM, the serial cable must be connected between the ECM serial port and the appropriate serial port on the computer. Turn on the computer, and if inspection reports are to be printed, the GRAPHICS command in DOS should be entered before proceeding with *TDWPOLY*. Run the *TDWPOLY* program. The main menu (Figure 14) will appear on the screen. Next,

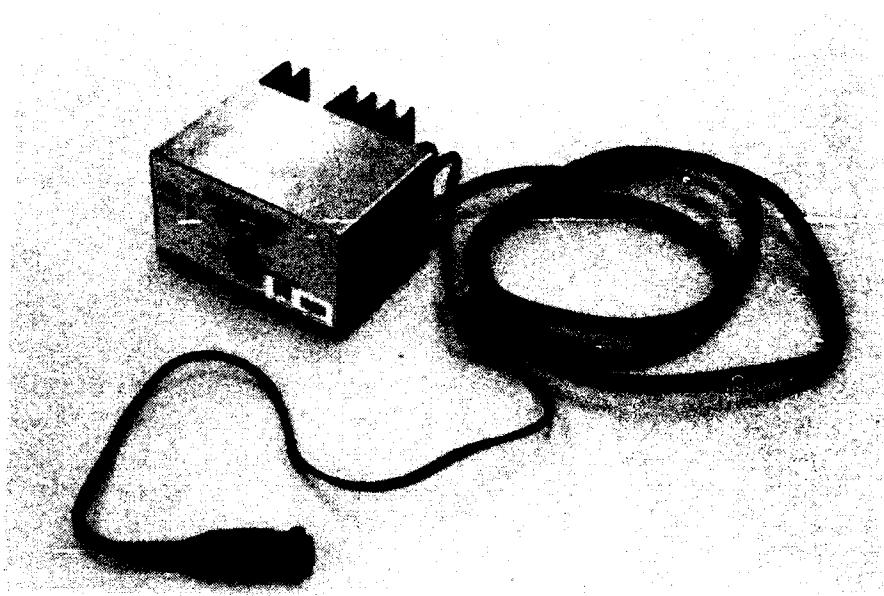


Figure 13. ECM Battery Charger.

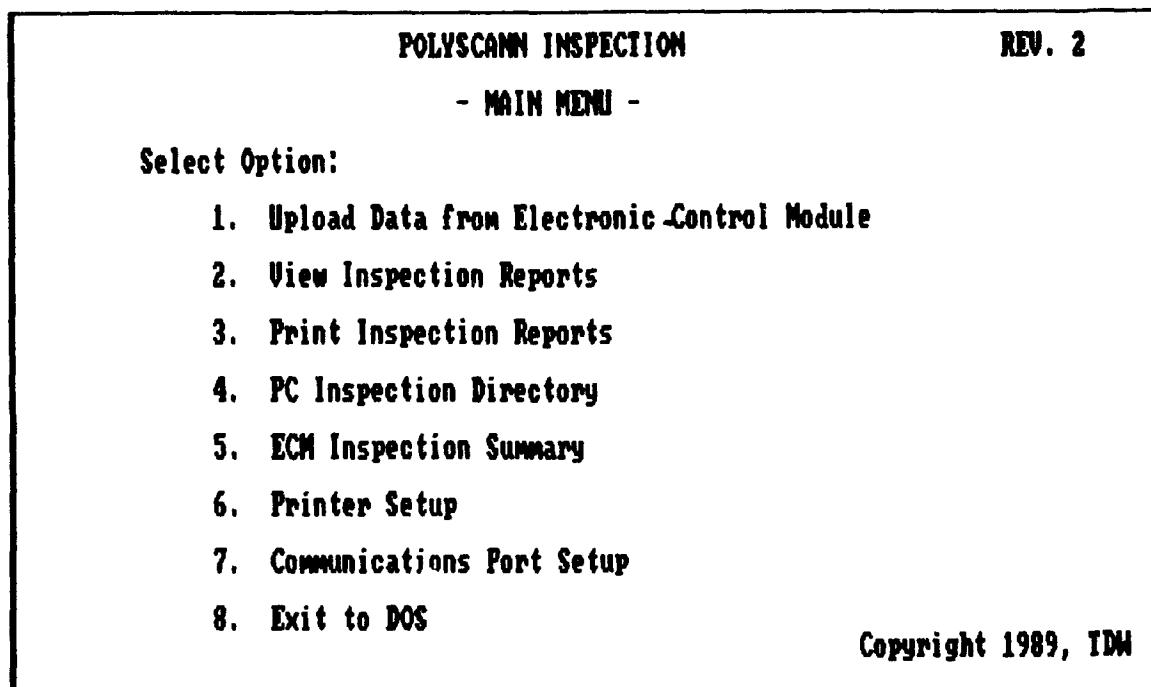


Figure 14. TDWPOLY Main Menu.

turn on the ECM. After proceeding through the self-test and startup status displays, select Option 2 to download inspection data. The ECM display should read:

**THERE ARE
XXX RECORDS
TO TRANSFER
< START/RESTART >**

The XXX is a placeholder for the number of inspections contained in the ECM that have not been downloaded. The most recent 120 inspections are always kept in the ECM memory. The program assumes that an inspection need no longer be counted after downloading. The window also tells whether the system is in the transfer or download portion of the program. START/RESTART must not be pressed until all downloading is complete.

On the computer, select Option 1 from the main menu. A prompt will appear, reminding the operator to prepare the ECM (if it has not been done), followed by a menu for selecting any number of desired compatible options. For example, numbers 4, 5, and 6 would select inspections performed by a specific operator on a specific line size that had passed. Figure 15 lists the upload options. Press RTN when ready. The screen shown in Figure 16 will appear. The operator must designate the drive (A, B, or C) to which inspection data is to be saved, and the appropriate directory. The default drive is A, or the last drive previously chosen. The directory defaults to the one most recently chosen. A directory name must be entered. After pressing RTN to enter the directory name, the option PgUp becomes available. This function permits making corrections to the drive or directory designated. After entry is complete, press RTN to proceed.

- UPLOAD OPTIONS -		REV. 2
<ul style="list-style-type: none">1. All records in memory2. Specific Insp # _____3. Range of Insp # _____ thru _____4. Specific Operator ID _____5. Pipe Size _6. Pass status7. Fail status8. Not Downloaded status9. Downloaded status		
PRESS LINE NUMBER TO TOGGLE SELECTION(S)		<Esc> Return <Rtn> Continue
Copyright 1989, TDW		

Figure 15. Upload Options.

The next screen, shown in Figure 17 permits the operator to enter additional information. Press RTN to continue. Two screens will appear in sequence letting the operator know that the inspections are being transferred. A message will indicate when transfer is complete.

In order to view inspection reports, select Option 2 from the main menu. The screen in Figure 18 will appear. Enter the desired drive, directory name, and inspection number to be viewed, then press RTN. The inspection report will appear on the screen. Figure 19 shows an inspection report screen. The diagram shows the cross-section of the fusion, oriented with 180 degrees at the top. A message on the left indicates either FLAWS FOUND or NO FLAWS FOUND. The NO FLAWS FOUND message will appear if the joint is acceptable. It is possible that flaws, not meeting rejection criteria will be shown on the inspection report, while the message indicates NO FLAWS FOUND. By using the PgUp and PgDn keys, other inspection reports in the directory can be viewed. These reports will appear in inspection number sequence. When reaching the end of a string of inspection numbers, the program will loop back to the start. To exit the viewing mode and return to the main menu, press ESC.

To initially set up a printer, select Option 6 on the main menu to check printer setup. A parallel graphics printer must be used for printouts. Use the up- or down-arrow to highlight the correct type of printer. Once this is complete, this printer setup will stay the same until changed again by a user. Press RTN to return to the main menu.

To print inspection reports, select Option 3 on main menu. The screen shown in Figure 20 will appear. Enter desired drive, directory name, and inspection number (as done for viewing a report). Press RTN to print the inspection report. If all the inspections in a given directory need to be printed, type in the word ALL on the inspection number line. Press ESC to return to the main menu.

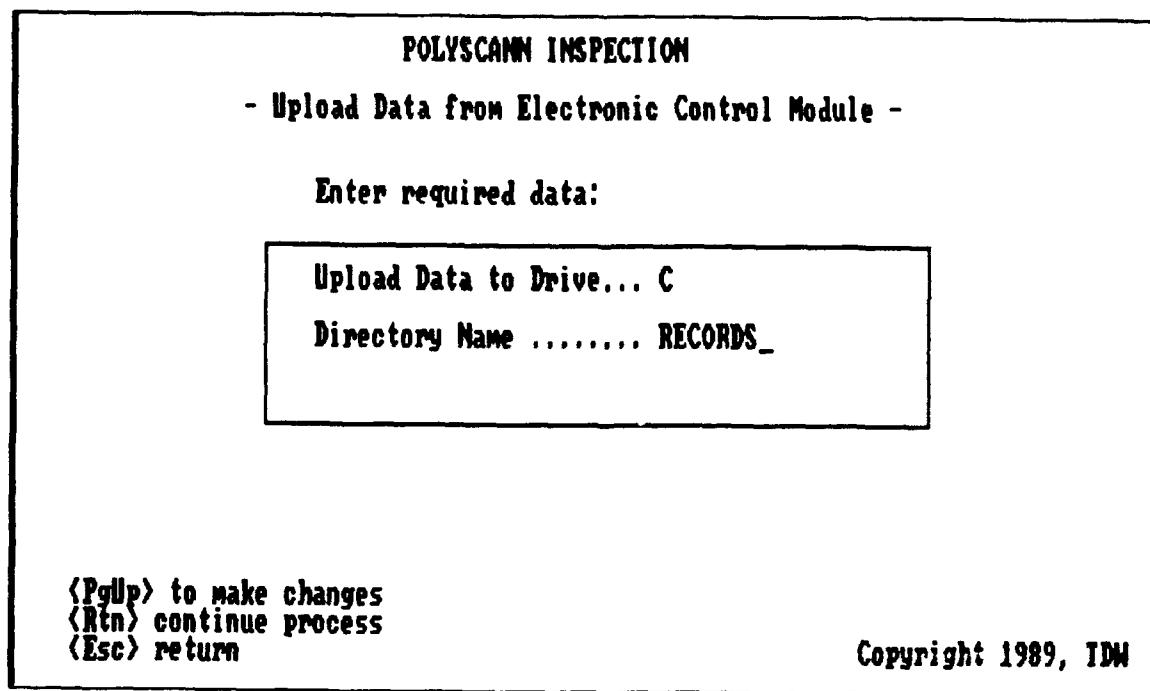


Figure 16. Save Options Screen.

POLYSCANN INSPECTION

REV. 2

- Upload Data from Electronic Control Module -

Enter required data:

Enter Inspectors Name: ORANGE MARSHALL

Enter Location or Job Name: USACERL

Enter Date of Inspection: 11/30/91

Enter General Comments: ENDS MISALIGNED

<PgUp> to make changes

<Rtn> to continue

<Esc> return to Main Menu

Copyright 1989, TDW

Figure 17. Inspection Data Screen.

- PC INSPECTION OPTIONS -

REV. 2

1. All records in memory
2. Specific Insp # _____
3. Range of Insp # _____ thru _____
4. Specific Operator ID _____
5. Pipe Size _
6. Pass status
7. Fail status

PRESS LINE NUMBER TO TOGGLE SELECTION(S)

**<Rtn> Continue
<Esc> Return
Copyright 1989, TDW**

Figure 18. View Selection Options.

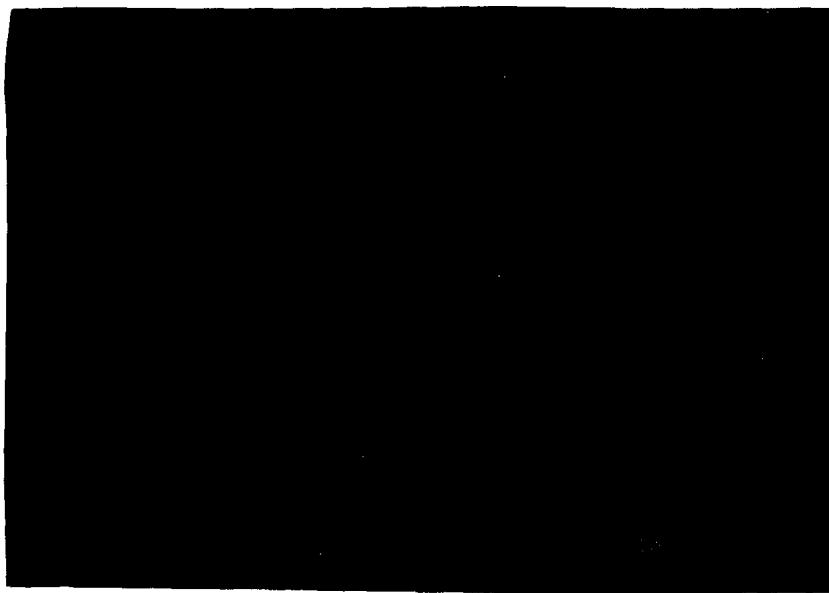


Figure 19. Inspection Report Screen.

POLYSCANN INSPECTION REPORT	
REV. 2	
- Print -	
Enter required data:	
Read Data from Drive... C	
Directory Name RECORDS	
Inspection # 000046	
<PgUp> to make changes <Rtn> continue process <Esc> return	
Copyright 1989, IDW	

Figure 20. Inspection Report Print Options.

4 LABORATORY TESTS

This chapter describes the laboratory testing that was conducted in order to evaluate the effectiveness and reliability of the Polyscann inspection system. The testing consisted of using the Polyscann system to evaluate butt-fused joints in 8 in. polyethylene pipe sections with various flaws manufactured in them. The ultrasonic testing was followed by tensile tests of samples prepared from the butt-fused joints in accordance with American Society for Testing and Materials (ASTM) D 638, *Standard Test Methods for Tensile Properties of Plastics*.

Specimen Preparation

Sample 8 in. pipe test specimens were prepared by the fuel distribution group of the exterior plumbing shop of the Fort Hood DEH maintenance division, and shipped to USACERL. Lengths of polyethylene pipe 2 to 3 ft long were joined together by butt-fusion joints. The samples contained butt-fusion joints with a variety of manufactured flaws in them. Appendix A lists the pipe samples that were manufactured and tested using the Polyscann inspection system, and reports the test results. Samples O-0, Y-0, and B-0 were continuous lengths of pipe without a butt joint. They were not evaluated using the Polyscann Ultrasonic Butt-Fusion Inspection System since there were no joints in the sections. The pipe colors indicate the relative density of the polyethylene used in the pipe construction. Black pipe indicates high density polyethylene, while orange and yellow pipe indicate medium density. (The orange color is being phased out and replaced exclusively with yellow to be consistent with international practices.)

Polyscann Evaluation Results

Pipe-joining conditions that resulted in detection of flaws by the Polyscann inspection system included dirt in the weld (Figure 21), misalignment of ends, too high a degree of heat used to melt the pipe ends before joining, and the pipe ends heated too long or not long enough before joining, and insufficient pressure used to join the pipe ends. Figures 22 and 23 are Polyscann reports for the sample heated to too high a temperature and the one in which insufficient pressure was used.

Pipe-joining conditions that resulted in no detection of flaws by the Polyscann inspection system included a joint without a designed flaw in it, joints formed using too much pressure, both under normal heat and insufficient heat, a joint contaminated with hydraulic oil before heating, and a weld with a tuft of grass inserted between the two joined sections (Figure 24). Except for the sample with the tuft of grass, the tensile tests also failed to detect the same flaws.

Tensile Testing

Following the Polyscann evaluation of the pipe samples, tensile test specimens were cut from the pipe samples, as indicated in Figure 25. A Sieburg Tensilcut specimen cutter was used to further modify the samples into dog-bone-shaped tensile specimens, as shown in Figure 26. This procedure standardized the gage length and width of each specimen. The specimens were kept in a laboratory at $23^{\circ}\text{C} \pm 2^{\circ}\text{C}$ for a minimum of 2 weeks before testing, then tested in the laboratory using a United Electromechanical testing machine. The relative humidity was not evaluated because tensile tests may be performed at ambient humidity and temperature (49 CFR 192.283(a)(3)). A constant crosshead speed of 0.25 in. per minute (ipm) was used for all of the tests. The load and crosshead displacement were output to a digital readout system. The load-versus-displacement graphs, an example of which is shown in Figure 27, were



Figure 21. Sample Joint With Dirt in Weld.

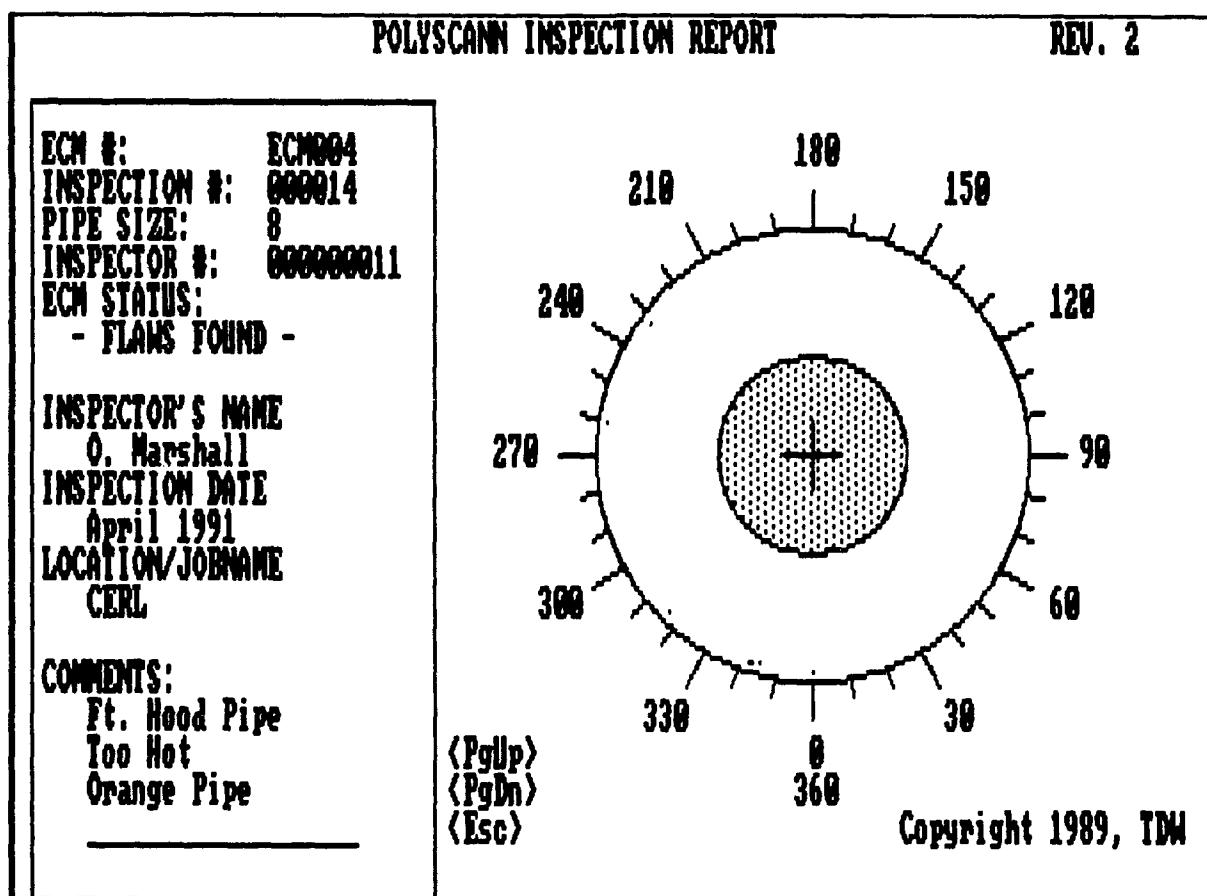


Figure 22. Inspection Report Screen for Weld Made With Excessive Heat.

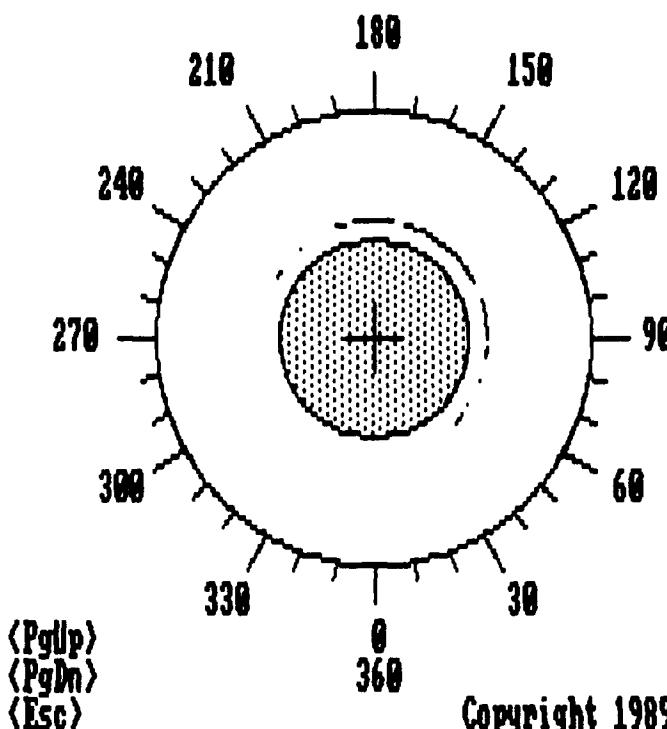
POLYSCANN INSPECTION REPORT

REV. 2

ECM #: ECM004
INSPECTION #: 000011
PIPE SIZE: 8
INSPECTOR #: 000000011
ECM STATUS:
- FLAWS FOUND -

INSPECTOR'S NAME
O. Marshall
INSPECTION DATE
April 1991
LOCATION/JOBNAME
CERL

COMMENTS:
Ft. Hood Pipe
Not Enough Pressure



<PgUp>
<PgDn>
<Esc>

Copyright 1989, TDW

Figure 23. Inspection Report Screen for Weld Made Under Insufficient Pressure.

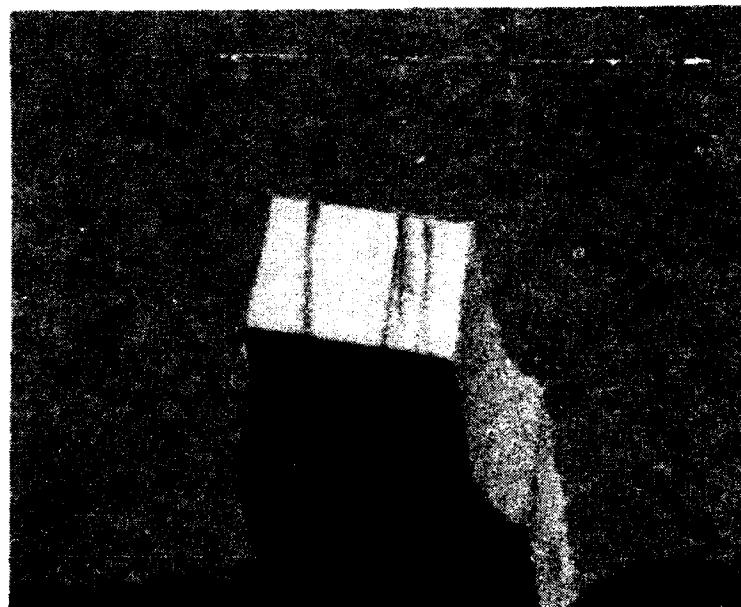
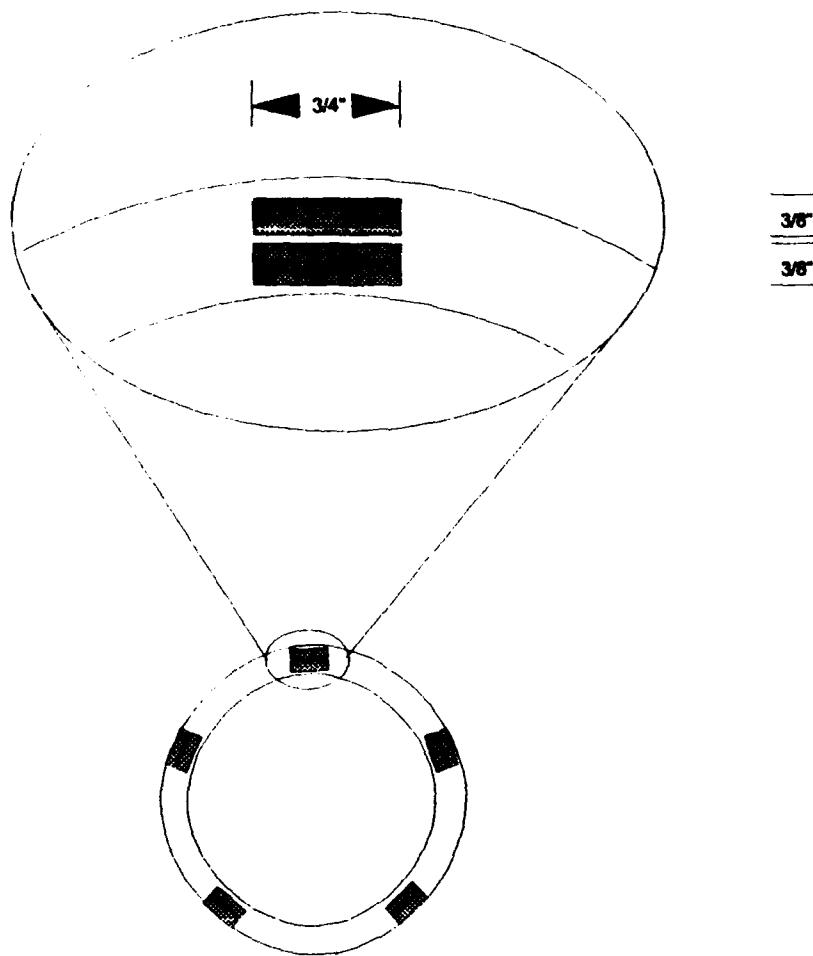


Figure 24. Sample Joint With Grass in Weld.

**End
View**



**Top
View**

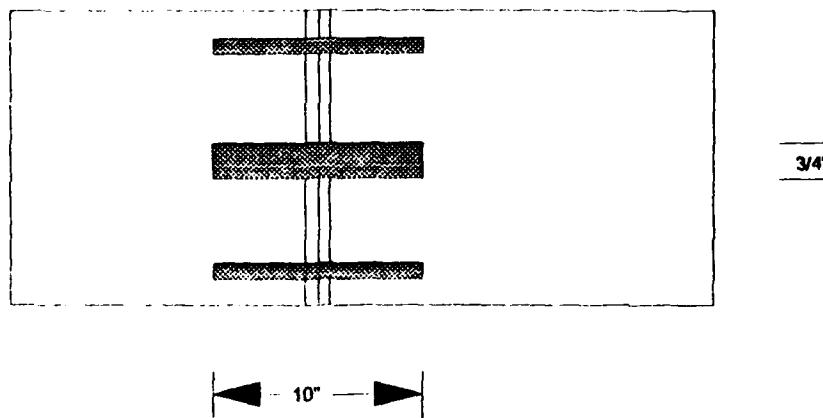


Figure 25. Specifications for Sample Joints Used in Tensile Tests.

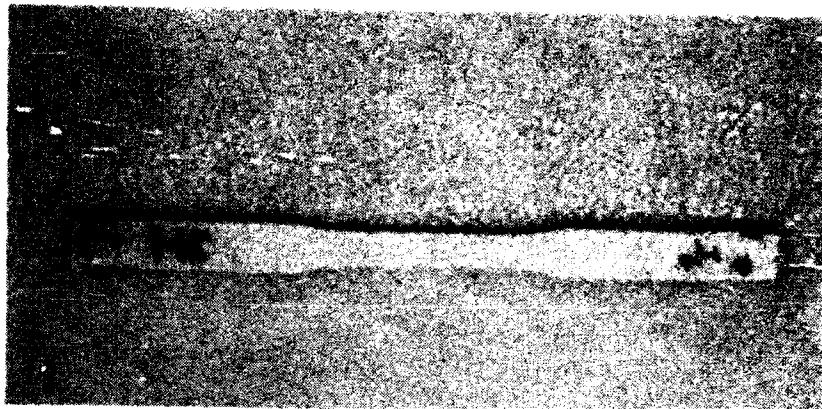


Figure 26. Specimens for Tensile Testing.

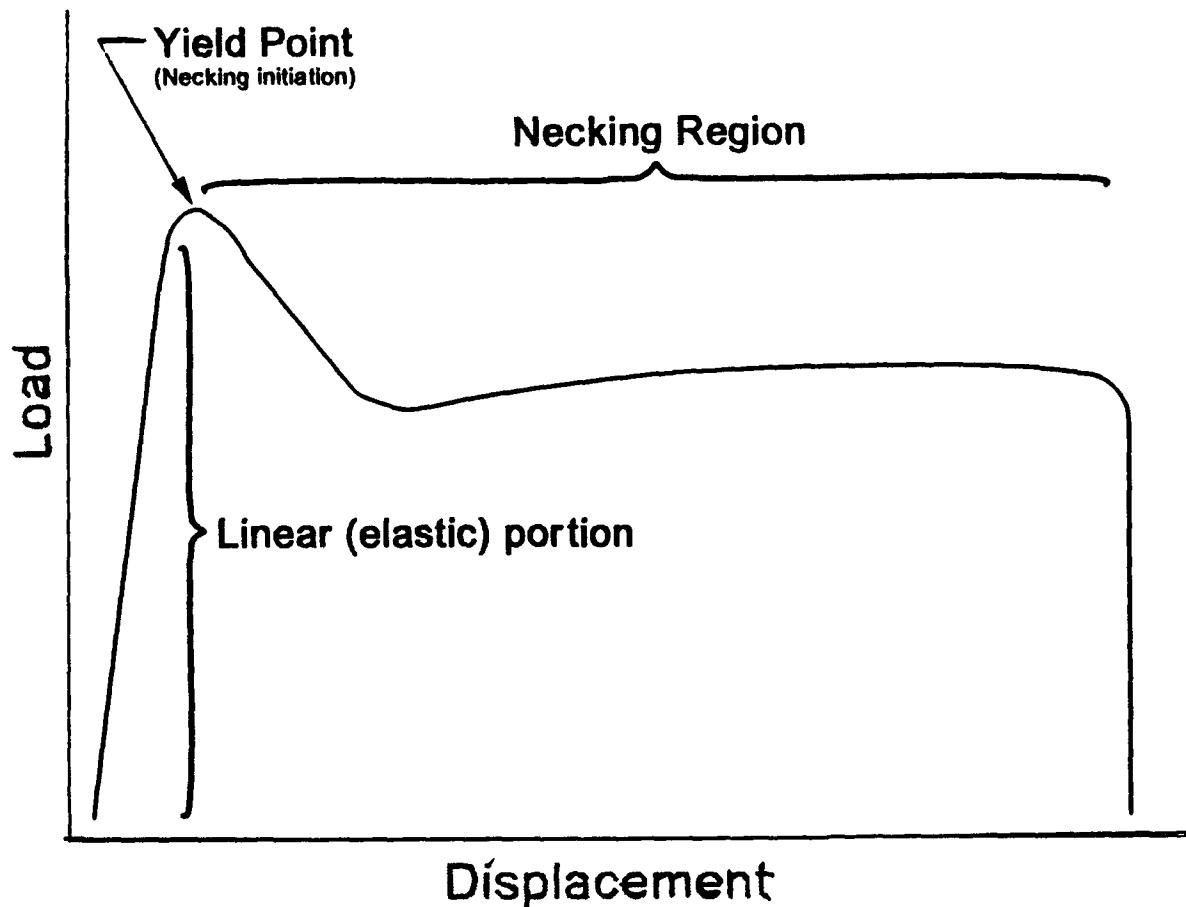


Figure 27. Typical Load-Versus-Displacement Graph.

used to determine the tensile strength at yield (or at break), the percent elongation, and the amount of necking (ductility or plastic flow) after yield or break for each specimen. The test results are summarized in Appendix B.

As indicated in Figure 27, the load reaches a peak, then reduces to a plateau that continues until the sample breaks. The peak value indicates the point where the necking phenomenon begins. At that point the cross-sectional area of the sample begins to decrease and the load required to pull the specimen is reduced. A true stress-strain curve that accounts for the differences in cross-sectional area would begin a plateau at that point, without any noticeable significant reduction in stress.

The thickness of each tensile specimen was measured and the cross-sectional area was calculated using the measured thickness and the known values of the other two gage dimensions. The tensile strength was calculated using the formula

$$\sigma = \frac{F}{A} \quad [\text{Eq } 1]$$

where σ = yield stress

F = maximum load measured for the specimen

A = minimum cross-sectional area of the sample.

The Young's modulus* was calculated by the formula

$$E = \frac{\sigma}{\epsilon} \quad [\text{Eq } 2]$$

where E = Young's modulus

σ = stress at a point on the linear (elastic) portion of the stress-strain curve

ϵ = associated strain.

To minimize error, the Young's modulus was calculated as a ratio of the change in stress in the elastic region to the corresponding change in strain.

The percent elongation was determined by the formula

$$\% \text{elongation} = \frac{\Delta l}{l_g} \times 100 \quad [\text{Eq } 3]$$

where Δl = change in the gage length of the specimen at break

l_g = original gage length.

Pass-Fail Criteria

There is one tensile test criterion that is necessary in order to pass a butt-fusion joint: a minimum of 25 percent elongation of the sample as required by 49 CFR 192.283(a). If the sample breaks before achieving the 25 percent elongation, the break must not be at the butt-joint. Other desirable criteria are (1) that there be no reduction in strength of the pipe material at the joint and (2) that there be some

* Young's modulus: the ratio of a simple tension stress applied to a material to the resulting strain parallel to the tension (McGraw-Hill Dictionary 1984).

necking of the sample to minimize the likelihood of catastrophic pipe failure. Figure 28 shows the normal necking phenomenon for polyethylene. Figure 29 shows a non-necking break at the butt-fusion joint. Pipe samples where both the inside and the outside tensile samples failed were judged as failures. Where only one of the two tensile samples failed, the joint was judged as marginally passing.

In order to determine the minimum allowable values for tensile strength for the different pipe grades tested, the mean and the standard deviation for the unfused pipe tensile samples were calculated. The mean was calculated by the formula

$$\mu = \frac{S_i}{n} \quad [Eq 4]$$

where S_i = an individual strength value
 n = is the total number of values.

The standard deviation was calculated by the formula

$$\sigma = \sqrt{\frac{\sum (S_i - \mu)^2}{n-1}} \quad [Eq 5]$$

Statistically, in order to select a minimum for the strength values that falls within a 95 percent confidence interval, the field width from the apparent mean must be determined. This is done using the relationship

$$w = 3.92 \frac{\sigma}{\sqrt{n}} \quad [Eq 6]$$

where w is the field width. By subtracting w from μ , the minimum allowable strength values were determined for the yield strength and tensile strength of each type of pipe. Table 1 is a summary of these values.

Table 1

**Minimum Values for Pass/Fail Criteria for
Pipe Grades Tested in the Laboratory**

Pipe Type	Tensile Strength (psi)	Modulus of Elasticity (psi)	Elongation (%)
Orange	2268.7	12512	60.0
Yellow	2240.5	15754	157.9
Black	2820.4	22978	193.7

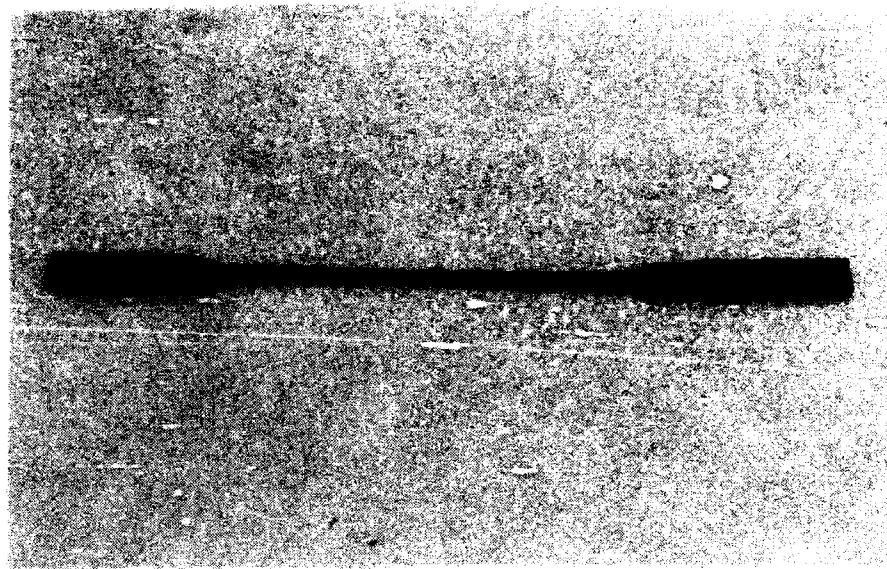


Figure 28. Example of Necking in Joint Specimen.

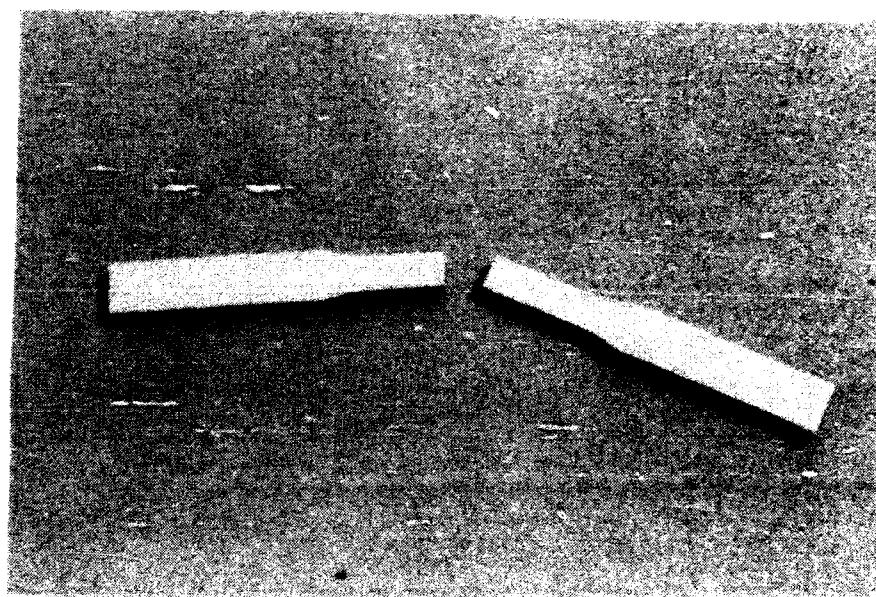


Figure 29. Example of Non-necking Failure in Joint Specimen.

Laboratory Analysis

Table 2 compares the Polyscann test results with the tensile test pass/fail criteria. One major shortcoming observed in using the Polyscann inspection system was that it failed to detect grass in the weld of pipe sample Y-2. A tuft of grass, about 1/8 in. in diameter, went through the weld and protruded out slightly, and was plainly visible on both the inside and the outside of the weld. As explained in Chapter 2, if the density of the grass is nearly the same as that of the polyethylene pipe, the equipment will not detect its presence in the weld. This was found to be the case for the Y-2 joint sample.

The data also indicate an agreement between the Polyscann results and the tensile tests. If *marginal* is defined as either pass or fail, the only disagreement in tensile test results is in pipe O-6 (not enough pressure used) where the tensile strength indicated the pipe passed. Except for grass in the weld, the Polyscann equipment indicated flaws in pipes O-3 (too high heat used), Y-3 (dirt in the weld), and B-1 (a good joint) while laboratory tensile tests indicated that they were good. Dirt was visible in the tensile samples, yet they passed. In this instance, the Polyscann system gave more reliable results than mechanical property tests in the laboratory—especially in the case of pipe Y-3.

Table 2

Pass/Fail Results of the Various Test Criteria for
The Pipe Samples Tested in the Laboratory

Pipe Identification Number	Polyscann Inspection Results	Elongation Criteria Results	Loss of Strength Results	Necking Criteria Results
O-0	N/A	Pass	N/A	Pass
O-1	Pass	Pass	Pass	Marginal
O-2	Pass	Marginal	Marginal	Marginal
O-3	Fail	Pass	Pass	Pass
O-4	Pass	Pass	Pass	Pass
O-5	Fail	Fail	Fail	Fail
O-6	Fail	Fail	Pass	Fail
O-7	Fail	Fail	Fail	Fail
O-8	Fail	Marginal	Pass	Marginal
Y-0	N/A	Pass	Marginal	Pass
Y-1	Pass	Pass	Pass	Pass
Y-2	Pass	Fail	Fail	Fail
Y-3	Fail	Pass	Pass	Pass
B-0	N/A	Pass	N/A	Pass
B-1	Fail	Pass	Marginal	Pass

5 DEMONSTRATION OF THE POLYSCANN SYSTEM

The Polyscann Ultrasonic Butt-Fusion Inspection System was successfully demonstrated at North Fort Hood, TX, on 16 to 18 September 1991. This chapter describes the demonstration. During the demonstration, 13 sections of 8 in. polyethylene pipe sections were assembled and tied (connected) into a previously installed 8 in. polyethylene natural gas pipeline. All of the butt-fusion joints in the new pipe assembly were inspected using the Polyscann system.

Polyethylene Butt-Fusion Inspection Process

The following procedure was used in performing the butt-fusions welds:

1. The butt-fusion machine was set into position and two lengths of pipe were brought up to the machine.
2. The pipe ends were examined. If scuffed, they were cut. If flawed, about 8 in. were cut off of the ends using a chain saw (Figure 30). This was necessary twice during the course of the demonstration—once due to a gouge on the outside surface of the pipe and once due to a deep cut (3 to 4 in.) in one end of the pipe.
3. Both pipe sections were clamped into place in the butt-fusion machine (Figure 31).
4. The trimming router was placed between pipe sections and turned on (Figure 32). The two sections were pressed together against the router using a hydraulic jack mechanism attached to one of the pipe clamps. Once a continuous ribbon of plastic was being removed from both sides of the router, indicating facial alignment, the pressure was released, and the router removed.
5. The two pipe ends to be joined were brought together to check for proper alignment. The inside and outside of the pipe ends were wiped clean with a wet cloth and then dried with another cloth.
6. A Teflon-coated heating plate was warmed to 500 °F (Figure 33) and placed between the two pipe ends. The pipe ends were touched to the heating plate and heated until a bead 3/16 in. to 1/4 in. wide was visible on the pipe (Figure 34).
7. The pressure forcing the pipe ends against the heating plate was quickly released and the heating plate removed.
8. The pipe ends were immediately pressed together until the beads of molten polyethylene at the ends of the pipes had rolled back to just touch the pipe surface (Figure 35). The joint was held until it cooled enough to touch for 10 to 20 seconds (which is about 110 °F for most people) indicating that the temperature of the pipe material was well below its softening point.

It was discovered on the first butt-joint tested, that if the valve lubricant and sealant was applied properly by forming about a quarter-inch bead of sealant between pipe seals along the plate seal (see Figure 6), the leakage of excessive amounts of coupling fluid observed in many of the laboratory tests could be eliminated.

The time required to set up the Polyscann equipment as described above and run a test scan was 9 minutes. Of that time, 4.5 minutes were spent applying the valve lubricant.



Figure 30. Pipe End Removal.



Figure 31. Butt-Fusion Machine.



Figure 32. Trimming Router in Place.

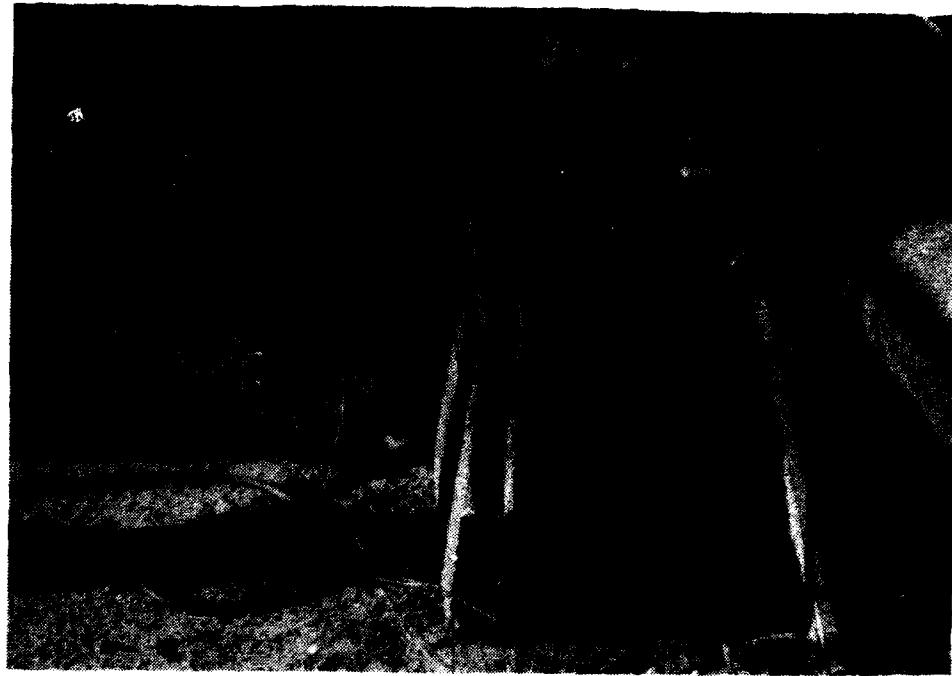


Figure 33. Teflon-Coated Heating Plate.

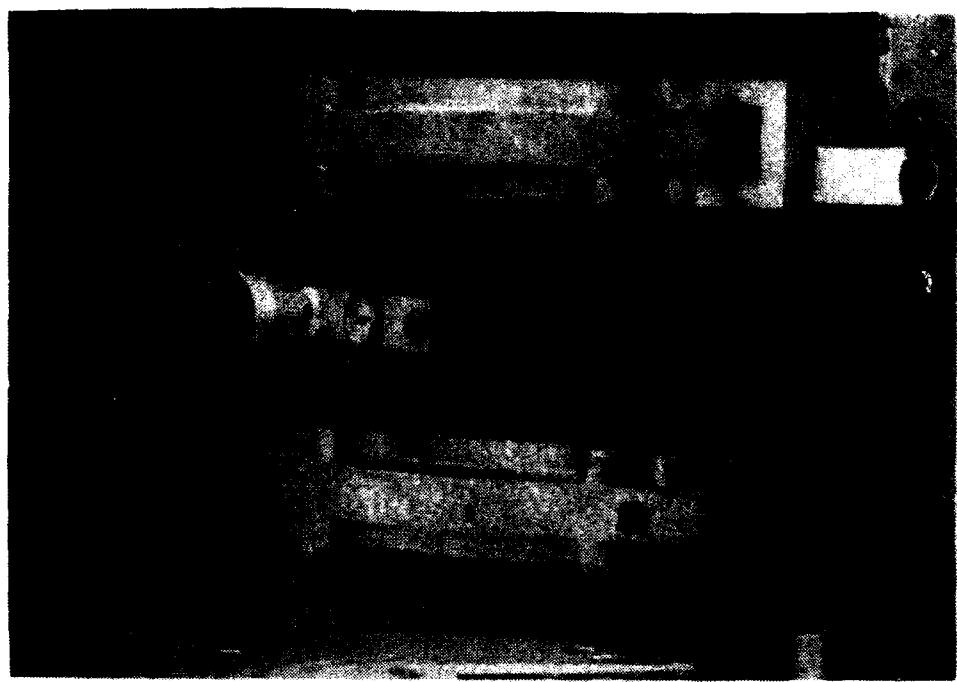


Figure 34. Molten Bead at Interface of Heating Iron and Pipe.

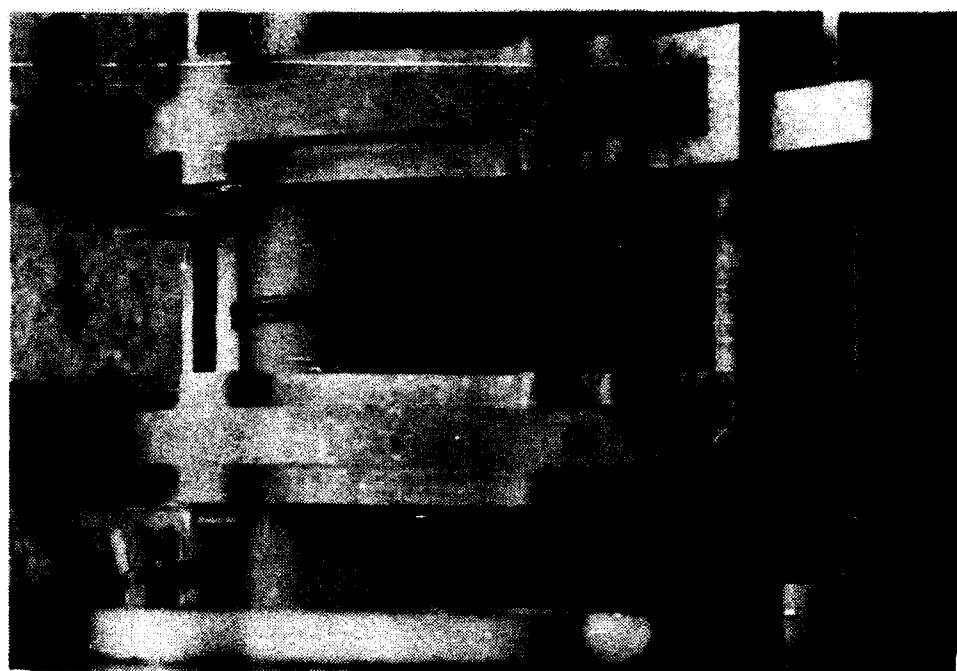


Figure 35. Fusion Bead.

During the course of the demonstration, 460 ft of pipe was assembled using 13 butt-fusion joints. All of the joints were examined using the Polyscann Ultrasonic Butt-Fusion Inspection System. The first 10 joints were evaluated by the USACERL principal investigator and the last three were evaluated by the Fort Hood DEH butt-fusion equipment operator. Out of the 13 joints, the Polyscann equipment detected two flaws in the four butt joints made the first day; no more flaws were found the following 2 days. The two flawed joints were removed, and nonflawed replacement joints were made.

Because of the size and locations of the flaws, there was a question as to whether these were flaws in the butt-fused joint or only in the inner joint bead. Subsequent discussions with engineers from T.D. Williamson, Inc., the manufacturer of the Polyscann system, indicate that each of the flaws was probably an air bubble in the inner plastic bead. The Williamson engineers said that if this were the case, the air bubble would not have affected joint integrity. At present there is no nondestructive way of confirming the presence of such air bubbles.

Only two difficulties arose during the course of the demonstration. On the first butt-joint evaluation, the equipment gave an error message but it was corrected by switching ends on the electronic cable between the electronic control module and the rotating assembly. To prevent the same thing from happening again, the ends of the electronic cables attached to the ECM were marked by wrapping them with a short length of tape. The other problem occurred when the battery in the electronic control module ran low and would not operate the equipment. This was alleviated by attaching the battery charger to the electronic control module and plugging it into the AC (alternating current) generator on the DEH vehicle for 20 minutes and recharging the batteries. That charge allowed testing of three more butt-fusion joints before lunch break, when the batteries were charged for an additional hour. This problem can be prevented by recharging the battery overnight after each day's work.

Use of the Polyscann Ultrasonic Butt-Fusion Inspection System provided 100 percent nondestructive testing of butt-joints in the polyethylene gas pipeline installed in the demonstration. Current industry practice is to conduct a destructive test of every fifth joint, as described in 49 CFR 192.285(a)(2)(iii). For 8 in. pipes, the test strap^{*} is normally 0.75 in. to 1 in. wide. This results in 2.5 percent to 4 percent of the butt-fused joint length being tested for soundness.

The use of the Polyscann equipment also benefitted the butt-fusion equipment operator by helping him to fine-tune his joining technique. Following the two flaw indications on the first day, the operator used the heating plate to create joint beads closer to the quarter-inch upper limit. This change in the operator's technique ensured that subsequent butt-joints were top quality. In addition, the joint tests gave the operator more confidence in his technique by helping to ensure the high quality of his work.

The pipeline installers were asked if they would use the Polyscann equipment if it were available to them when installing pipelines. They said that it would depend on whether its use was required. Although the installers have plenty of time to test a joint while the next one is cooling, user feedback suggests that installers would probably not test the joints on their own initiative. Therefore, use of this technology would probably have to be made mandatory to ensure that it is used in the field.

*strap: the strip of plastic sampled from the butt-fusion joint.

Benefits of the Polyscann System

Some benefits of the Polyscann system noted during the demonstration include:

1. It is a portable unit that can easily be transported and used at a remote worksite
2. It uses a nondestructive method to evaluate butt-fusion joints
3. It evaluates 100 percent of each butt-fusion joint
4. It enables an operator to evaluate every butt-fusion joint made without interfering with pipeline productivity
5. It provides a computerized database of each evaluation
6. It can serve as a training aid for gas pipeline installers by immediately showing the quality of their work
7. It can provide significant cost savings on repairs due to poor workmanship prior to putting the pipe in the ground. (Fort Hood has been forced to replace 3.5 miles of new 8 in. polyethylene gas pipeline at an estimated cost of \$500,000 due to poor installation workmanship. Most or all of this cost may have been avoided by use of the Polyscann system on the joints.)

Drawbacks

Some drawbacks to using the Polyscann system include:

1. It is costly to buy (Table 3).
2. It is extra work for the pipe-laying crew, especially if they have not already been tasked to perform the normal destructive testing required for pipeline installation.

Table 3
Costs for Polyscann System, 1990

POLYSCANN Basic Unit	\$8240.00
Electronic Control Module	
Support Module Cables	
Hoses	
Computer Software	
Instruction Manual	
Couplant Fluid (Case)	
8" System	\$5900.00
Static Ring	
Rotating Ring	
Carrying Case	
6" System	\$5000.00
Static Ring	
Rotating Ring	
Carrying Case	
Couplant Fluid	\$50.00
4 Gallons - Case	

6 CONCLUSIONS AND RECOMMENDATIONS

The demonstration of the Polyscann Ultrasonic Butt-Fusion Inspection System at Fort Hood was highly successful. It provided an efficient way to nondestructively test an entire butt-fusion joint—not just a small percentage of it. The system provided a computerized record of the joint cross-section and status, and was demonstrated to be easy to use by pipeline technicians. Laboratory tests indicated that the equipment provided reliable test results, except for low-density contaminants (such as dried grass) in a weld.

Other benefits of using the Polyscann system include portability and ease of transportation to the worksite, the ability to evaluate every butt-fusion joint on a pipeline without interfering with pipeline operations, and the ability to easily create, store, and reproduce a record of each evaluation. Furthermore, the system in effect worked as a training aid for gas pipeline installers by giving them immediate feedback on weld quality. By giving the installers the ability to correct mistakes before putting the pipe into the ground, the system demonstrated the potential to save the Army money on pipeline repairs due to poor workmanship.

Ensuring the use of this technology by pipeline contractors and technicians would probably require its use being specified in the contract documentation or the applicable CEGS.

Since the conduct of this laboratory test and field demonstration, T.D. Williamson, Inc., has stopped manufacturing the system tested in this demonstration and is redesigning it to be smaller and lighter so it is portable by one person. Another planned upgrade is to make the system more able to detect low-density materials such as grass. The manufacturer has not yet projected a release date for the next generation of this system or any cost changes arising from the redesign.

It is recommended that (1) the next-generation Polyscann Ultrasonic Butt-Fusion Inspection System be evaluated in a similar manner when it becomes available for purchase to assure acceptability, (2) an *in-situ* repair technique be developed that would enable nondestructive repair of any joints in which flaws are indicated by the Polyscann Ultrasonic Butt-Fusion Testing System, and (3) purchase and use of the Polyscann equipment system be supported at Army installations for installation of polyethylene gas pipelines. Since the rig assemblies for each size of pipe cost a substantial amount of money, and since relatively few gas pipelines are installed simultaneously, it would be most cost-effective for MACOM engineers to purchase one or two systems, maintain them at a central location, and support their use with a qualified operator at any installation where polyethylene gas pipelines are being installed.

METRIC CONVERSION FACTORS

$^{\circ}\text{F} =$	$(^{\circ}\text{C} + 17.78) \times 1.8$
1 in. =	2.54 cm
1 gal =	3.785 l
1 mile =	1.609 km
1 psi =	6.89 kPa

REFERENCES

Code of Federal Regulations (CFR) Title 49 Subtitle B - Other Regulations Relating to Transportation Part 192 - Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards; subpart F - Joining of Materials Other Than by Welding (192.283 - Plastic Pipe: Qualifying Joining Procedures).

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Frederick, J.R., *Ultrasonic Engineering* (John Wiley & Sons, Inc., New York, 1965), pp 2-7.

The American Heritage Dictionary, Second College Edition (Houghton Mifflin Company, Boston, 1982), pp 1165-1312.

Ultrasonic Testing of Materials, Krautkramer, J., and Krautkramer, H. (Springer-Velag, New York, 1977), p 193.

APPENDIX A: Tabulation of Polyscann Inspection Results for Pipes Tested in the Laboratory

Pipe Identification Number	Pipe Description	Type Polyethylene	Type of Flaws in Pipe Joint	Polyscann Inspection Results
O-0	Orange 8" Pipe	PE 2306	N/A*	N/A*
O-1	Orange 8" Pipe	PE 2306	None	No Flaws Found
O-2	Orange 8" Pipe	PE 2306	Normally Too Much Pressure	No Flaws Found
O-3	Orange 8" Pipe	PE 2306	Too Hot	Flaws Found
O-4	Orange 8" Pipe	PE 2306	Lo Temp. High Pressure	No Flaws Found
O-5	Orange 8" Pipe	PE 2306	Ends Misaligned	Flaws Found
O-6	Orange 8" Pipe	PE 2306	Not Enough Pressure	Flaws Found
O-7	Orange 8" Pipe	PE 2306	Heat Too Long	Flaws Found
O-8	Orange 8" Pipe	PE 2306	Not Enough Heat	Flaws Found
Y-0	Yellow 8" Pipe	PE 2406	N/A*	N/A*
Y-1	Yellow 8" Pipe	PE 2406	Oil in Weld	No Flaws Found
Y-2	Yellow 8" Pipe	PE 2406	Grass in Weld	No Flaws Found
Y-3	Yellow 8" Pipe	PE 2406	Dirt in Weld	Flaws Found
B-0	Black 8" Pipe	PE 3306	N/A*	N/A*
B-1	Black 8" Pipe	PE 3306	None	Flaws Found

* Sample taken from pipe section with no butt-fusion joint.

APPENDIX B: Tabulation of the Laboratory Mechanical Tensile Test Results

Pipe I.D./ Sample I.D.	Tensile Strength (psi)	Modulus of Elasticity (psi)	Elongation (%)	Necking (in.)
O-0				
1-O	2462.9	13776	109.8	2.1
1-I	2418.8	14403	>244*	6.5
2-O	2557.0	16495	206.3	5.1
2-I	3266.0	22774	184.3	4.6
3-O	3289.1	23985	66.8	1.2
3-I	3173.4	21119	142.5	3.3
4-O	2494.3	16147	207.9	5.2
4-I	2500.5	14150	84.3	1.6
5-O	2505.4	15711	120.1	2.6
5-I	2530.5	14299	106.1	2.1
O-1				
1-O	2531.2	16639	29.8	0
1-I	2459.9	12133	70.7	1
2-O	2687.2	18951	36.7	0.2
2-I	2519.3	15583	71.6	1.2
3-O	2489.3	16744	35.8	0.2
3-I	2623.9	15341	71.2	1.2
4-O	2329.2	16639	45.3	0.5
4-I	2663.0	17175	138.4	3.2
5-O	2505.4	19518	36.3	0.3
5-I	2530.5	14964	84.2	1.6

* >244 in the elongation column indicates a value exceeding the capability of the test equipment to measure.
** A value of zero in the necking column indicates catastrophic failure of the sample before any necking occurred.

Pipe I.D./ Sample I.D.	Tensile Strength (psi)	Modulus of Elasticity (psi)	Elongation (%)	Necking (in.)
O-2				
1-O	2388.7	17064	28.5	0
1-I	1542.5	15252	243.0	6.2
2-O	2489.6	15772	29.3	0
2-I	2486.6	14539	64.3	1
3-O	2622.3	17733	35.4	0.2
3-I	2594.7	14573	70.6	1.1
4-C	2658.2	17509	35.8	0.2
4-I	2497.0	14220	59.9	0.8
5-O	2313.5	16915	19.4	0
5-I	2655.5	14871	220.8	5.5
O-3				
1-O	2602.4	19465	49.8	0.7
1-I	2518.1	16557	44.8	0.5
2-O	2714.5	19988	49.4	0.7
2-I	2730.1	21039	61.7	1.1
3-O	2767.2	23063	41.0	0.5
3-I	2734.8	21223	44.6	0.7
4-O	2487.2	16454	138.0	3.2
4-I	2666.7	19065	55.5	0.9
5-O	2728.3	21774	47.9	0.7
5-I	2646.0	16298	51.6	0.7

* >244 in the elongation column indicates a value exceeding the capability of the test equipment to measure.

Pipe I.D./ Sample I.D.	Tensile Strength (psi)	Modulus of Elasticity (psi)	Elongation (%)	Necking (in.)
O-4				
1-O	2567.9	21775	49.6	0.7
1-I	2540.7	19656	76.9	1.5
2-O	2776.1	21223	52.7	0.8
2-I	2666.9	24153	54.4	0.9
3-O	2637.5	20205	54.0	0.8
3-I	2589.8	17345	50.5	0.7
4-O	2683.7	18964	54.7	0.8
4-I	2659.6	17599	43.2	0.5
5-O	3009.0	19775	51.9	0.7
5-I	2717.3	19215	43.3	0.5
O-5				
1-O	2039.9	19988	11.5	0
1-I	1544.1	19637	9.2	0
2-O	2649.7	18396	25.9	0
2-I	2354.0	22313	14.4	0
3-O	2304.2	16965	16.5	0
3-I	2701.4	20671	21.1	0
4-O	2270.9	18554	14.6	0
4-I	1856.2	18608	10.9	0
5-O	2223.6	19474	14.8	0
5-I	1635.8	17380	9.2	0

* >244 in the elongation column indicates a value exceeding the capability of the test equipment to measure.

Pipe I.D./ Sample I.D.	Tensile Strength (psi)	Modulus of Elasticity (psi)	Elongation (%)	Necking (in.)
O-6				
1-O	2512.1	19116	21.6	0
1-I	2503.0	21249	16.6	0
2-O	2598.3	19065	34.4	0.3
2-I	2719.8	20295	21.4	0
3-O	2640.7	15837	24.3	0
3-I	2729.2	18859	24.2	0
4-O	2626.8	17408	28.0	0.05
4-I	2457.6	20042	17.4	0
5-O	2628.6	19013	35.0	0.3
5-I	2749.3	21621	21.6	0
O-7				
1-O	2577.5	18450	29.3	0.1
1-I	1592.8	19624	9.5	0
2-O	2600.3	20042	23.3	0
2-I	1345.4	20536	7.5	0
3-O	1634.0	18758	10.3	0
3-I	1636.7	19226	8.9	0
4-O	2172.9	17204	16.6	0
4-I	1715.0	21658	10.0	0
5-O	2569.7	15353	47.6	0.5
5-I	1934.9	21940	11.0	0

* >244 in the elongation column indicates a value exceeding the capability of the test equipment to measure.

Pipe I.D./ Sample I.D.	Tensile Strength (psi)	Modulus of Elasticity (psi)	Elongation (%)	Necking (in.)
O-8				
1-O	2731.1	21998	73.5	1.4
1-I	2745.1	20799	27.8	0.05
2-O	2717.4	18651	34.7	0.3
2-I	2659.6	21296	22.2	0.05
3-O	2674.8	16662	215.0	5.5
3-I	2760.9	21611	28.1	0.1
4-O	2717.4	20982	44.7	0.6
4-I	2736.7	16822	30.9	0
5-O	2690.8	18651	34.7	0.2
5-I	2394.8	23832	14.1	0

* >244 in the elongation column indicates a value exceeding the capability of the test equipment to measure.

Pipe I.D./ Sample I.D.	Tensile Strength (psi)	Modulus of Elasticity (psi)	Elongation (%)	Necking (in.)
Y-0				
1-O	2417.3	23903	>244*	6.5
1-I	2393.8	17159	>244	6.5
2-O	2505.5	19233	139.5	3.4
2-I	2585.0	28301	111.1	2.7
3-O	2361.9	19127	>244	6.5
3-I	2512.9	18880	>244	6.5
4-O	2350.5	22373	>244	6.5
4-I	2542.7	22878	>244	6.5
5-O	2070.1	16291	>244	6.5
5-I	2483.2	18815	>244	6.5
Y-1				
1-O	2550.2	21580	51.4	0.8
1-I	2572.8	20219	48.0	0.7
2-O	2440.6	19526	39.3	0.4
2-I	2599.3	20132	27.3	0.1
3-O	24585	20290	63.8	1.2
3-I	2578.3	23213	42.9	0.6
4-O	2576.5	21623	>244	6.5
4-I	2555.4	20235	72.1	1.4
5-O	2491.2	18602	72.0	1.4
5-I	2574.0	19655	94.1	2.1

* >244 in the elongation column indicates a value exceeding the capability of the test equipment to measure.

Pipe I.D./ Sample I.D.	Tensile Strength (psi)	Modulus of Elasticity (psi)	Elongation (%)	Necking (in.)
Y-2				
1-O	1444.8	21474	8.7	0
1-I	1138.5	24153	5.5	0
2-O	2451.0	17782	97.6	2.2
2-I	2818.6	20087	50.9	0.8
3-O	2444.3	20567	>244	6.5
3-I	2614.4	17691	69.9	1.4
4-O	26084	16267	95.5	2.1
4-I	2609.5	21262	48.7	0.8
5-O	2536.1	17467	160.7	4
5-I	2751.0	21128	67.7	1.3
Y-3				
1-O	2487.3	17830	148.5	3.6
1-I	2451.0	18303	26.1	0.1
2-O	2395.2	16097	77.6	1.6
2-I	2549.7	21370	>244	6.5
3-O	2459.8	18245	116.8	2.7
3-I	2485.6	19346	77.7	1.6
4-O	2534.7	19182	80.0	1.9
4-I	2437.7	14299	45.0	0.6
5-O	24972	17733	63.3	1.2
5-I	2602.9	19535	97.0	2.2

* >244 in the elongation column indicates a value exceeding the capability of the test equipment to measure.

Pipe I.D./ Sample I.D.	Tensile Strength (psi)	Modulus of Elasticity (psi)	Elongation (%)	Necking (in.)
B-0				
1-a	2806.7	23231	170.4	6.5
1-b	2878.1	26257	>244	2.2
2-a	2994.3	26358	>244	2
2-b	2994.3	27865	>244	1
3-a	2920.4	25920	193.8	6.5
3-b	2946.5	27207	>244	0.8
4-a	2953.1	22844	205.0	5.3
4-b	3055.8	28765	>244	1
5-a	2867.5	25292	>244	6.5
5-b	2825.8	25570	>244	1.7
B-1				
1-O	2744.1	13954	323.6	8.5
1-I	2854.9	21353	101.2	2.2
2-O	2803.4	18550	96.7	2
2-I	2991.4	27442	56.6	1
3-O	2738.8	18401	248.2	6.5
3-I	2936.1	26524	50.5	0.8
4-O	3819.9	26903	208.5	5.3
4-I	2833.4	27448	56.2	1
5-O	2822.3	25438	245.3	6.5
5-I	2897.0	22757	82.7	1.7

* >244 in the elongation column indicates a value exceeding the capability of the test equipment to measure.

ABBREVIATIONS AND ACRONYMS

AC	<i>alternating current</i>
CEGS	<i>Corps of Engineers Guide Specifications</i>
DEH	<i>Directorate of Engineering and Housing</i>
ECM	<i>electronic control module</i>
FEAP	<i>Facilities Engineering Applications Program</i>
Hz	<i>Hertz</i>
ID	<i>identification</i>
ipm	<i>inches per minute</i>
MACOM	<i>major Army command</i>
mHz	<i>milliHertz</i>
MHz	<i>megaHertz</i>
NDT	<i>nondestructive testing</i>
OCE	<i>Office of the Chief of Engineers</i>
USACE	<i>U.S. Army Corps of Engineers</i>

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